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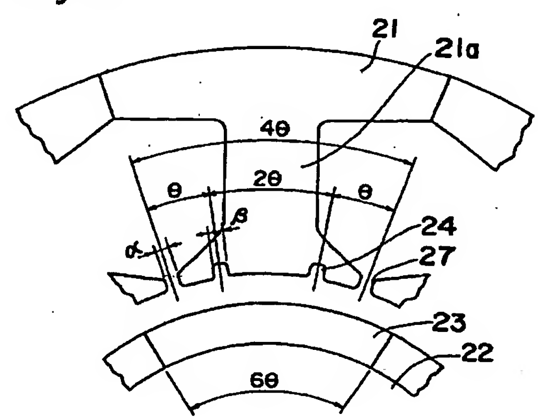
(54) **MOTOR**

(57) In the permanent magnet motor of the present invention, assuming that P is an integer not smaller than one, then the number of magnetic poles of a rotor 22 is set to 2P, and the number of salient poles of a stator field core 21 is set to 3P. Then, the salient pole section 21a of each stator field core 21 is provided with two supplemental grooves 24. Assuming herein that a salient pole magnetic interpolar angle is 4θ, then the two supplemental grooves 24 of each salient pole section 21a are arranged in positions at angles of θ and 3θ with respect to the center of a winding slot 27 in the circumferential direction of the rotor. With this structure, a fundamental wave component of a cogging torque is removed and a permanent magnet motor having a low cogging torque is provided.

Fig. 5



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Description

TECHNICAL FIELD

The present invention relates to a motor magnet structure, and in particular, to a permanent magnet motor for use in machine tools, garment manufacturing machines, robots and the like.

BACKGROUND ART

The permanent magnet motor which is one of the motors has been conventionally well known. In regard to the permanent magnet motor, one whose stator field core is provided with a supplemental groove for reducing a cogging torque is disclosed in the document of Japanese Patent Publication No. SHO 58-42708, and a further one whose stator field core is provided with a supplemental salient pole and a supplemental groove is disclosed in the document of Japanese Patent Publication No. HEI 6-81463 and so on.

Fig. 23A is a view showing an example of the construction of a prior art permanent magnet motor provided with a supplemental groove for reducing the cogging torque, while Fig. 24 is an enlarged view showing the essential part of the motor shown in Fig. 23A.

As shown in Fig. 23A, this prior art permanent magnet motor is substantially constructed of a stator field core 1 and a rotor 2. In this case, six permanent magnetic poles 3 are fixed on the periphery of the rotor 2. That is, the rotor 2 is the permanent magnet rotor. Further, a plurality of supplemental grooves 5 are formed at regular intervals in a rotor circumference direction at a salient pole section 1a of the stator field core 1. It is to be noted that a winding slot 7 is provided between adjacent stator field cores 1 (salient pole sections 1a).

As shown in Fig. 24, in the above permanent magnet motor, assuming that P is an integer not smaller than one, then the number of the permanent magnetic poles 3 (magnetic pole count) fixed to the rotor 2 is generally set to 2P, and the number of the salient pole sections 1a (salient pole count) of the stator field core 1 is set to 3P. Further assuming that an angle corresponding to the length of the stator field core 1 in the rotor circumference direction is 3θ, then two supplemental grooves 5 of the salient pole section 1a of the stator field core 1 are arranged so that an angle corresponding to the interval in the rotor circumference direction is θ. In this case, an angle corresponding to the length in the rotor circumference direction of each permanent magnetic pole 3 is 4.5θ. In this case, when the supplemental grooves 5 are not provided, the degree of the lowest common multiple of the number of the permanent magnetic poles 3 (magnetic pole count) and the number of the salient pole sections 1a (salient pole count) of the stator field core 1 is the cogging torque per rotation of the rotor 2, and the cogging torque is 6P (the lowest common multiple of 2P and 3P) per rotation in this case.

In contrast to this, when the supplemental grooves 5 are provided, the salient pole sections are apparently increased in number, and the cogging torque is 18P (the lowest common multiple of 2P and $3 \times 3P$) per rotation in this case. However, in this case, actually a triple higher harmonic (the degree of 18P per rotation) is superimposed on a fundamental wave (the degree of 6P per rotation).

Specifically, in a case where P = 3, the fundamental wave of the cogging torque has 18 waves per rotation (one wave per 20°). However, a waveform including the triple higher harmonic on its fundamental wave results since the supplemental grooves 5 are provided as shown in Fig. 23B, when a cogging torque waveform 6b does not become a cogging torque having only the higher harmonic component of 54 waves per rotation.

As described above, the apparent cogging torque is reduced by incorporating the high-degree components into the fundamental wave component of the cogging torque with the provision of the supplemental grooves at regular intervals in the prior art stator field core, however, it does not have the optimum supplemental groove arrangement capable of sufficiently removing the fundamental wave component.

Furthermore, in the prior art permanent magnet motor in which the stator field core is provided with the supplemental salient pole section and the supplemental groove, there is the problem that the winding is hard to be achieved since the supplemental salient pole section is formed on the stator field core. For the purpose of improving this problem, there can be considered a measure for dividing the stator field core into a plurality of cut type cores. However, in this case, the cores are increased in number to incur an increased number of assembly processes and cause a problem that the structural strength of the stator field core is weakened.

Furthermore, the prior art permanent magnet motor has the problem that the torque pulsation increases depending on the control system even though its cogging torque is low.

The present invention has been developed to solve the aforementioned conventional problems, and its object is to provide a permanent magnet motor having a low cogging torque or a permanent magnet motor having a reduced torque pulsation capable of arranging supplemental grooves in optimum positions and being assembled through the assembly processes equivalent in number to those of the prior arts while assuring the structural strength equivalent to those of the prior arts even when the stator field core is divided into cut type cores.

DISCLOSURE OF THE INVENTION

According to the motor of the present invention developed for solving the aforementioned problems, assuming that N is an odd number not smaller than three, then the slot angle of the salient pole section of

the stator field core is set to 1/N with respect to the angle of the permanent magnet magnetic pole of the permanent magnet rotor when no supplemental groove is provided. When a supplemental groove is provided, assuming that P is an integer not smaller than one, then the number of the permanent magnet magnetic poles (magnetic pole count) of the rotor is set to 2P, the number of the salient pole sections (salient pole count) of the stator field core is set to 3P and the salient pole section of each stator field core is provided with two supplemental grooves. When the angular interval between salient pole sections is 4θ, the supplemental grooves are arranged in positions at angles of θ and 3θ with respect to the center of the winding slot. With this arrangement, a motor having a low cogging torque is obtained.

Furthermore, with a skew structure corresponding to motor control, a permanent magnet motor having a low cogging torque or a permanent magnet motor having a small torque pulsation can be obtained.

More specifically, according to a first aspect of the present invention, there is provided a motor characterized in that the number of permanent magnet magnetic poles of a rotor (magnetic pole count) is set to 2P and the number of salient poles of a stator field core (salient pole count) is set to 3P with respect to an integer P of not smaller than one and a slot angle of a salient pole section of the stator field core is set to 1/N of the angle of one permanent magnet magnetic pole with respect to an odd number N of not smaller than three. In this motor, a force exerted in the circumferential direction on the stator magnetic pole surface is balanced in any position during the rotation at each salient pole section. Thus, according to the first aspect of the present invention, a permanent magnet motor having a low cogging torque can be provided when the stator field core is either an integrated type core or a divided type core.

According to a second aspect of the present invention, there is provided a motor characterized in that the number of permanent magnet magnetic poles of a rotor is set to 2P and the number of salient poles of a stator field core is set to 3P with respect to an integer P of not smaller than one, the salient pole section of each stator field core is provided with two supplemental grooves, and assuming that an angular interval between salient pole sections is 4θ, then the two supplemental grooves are arranged in positions at angles of θ and 3θ with respect to a center of a winding slot in the circumferential direction of the rotor. In this motor, since the supplemental grooves are provided, the area facing the magnetic pole can be widened. Thus, according to the second aspect of the present invention, the torque can be increased while suppressing the cogging torque.

In the motor of the second aspect, it is preferred that the two supplemental grooves have their centers arranged in the positions at angles of θ and 3θ with respect to the center of the winding slot in the circumferential direction of the rotor. In this case, the positions of the supplemental grooves become more appropriate, so that the cogging torque can be further reduced. With this appropriate arrangement, the cogging torque can be effectively suppressed.

In the motor of the second aspect, the two supplemental grooves may have their end portions on the salient pole magnetic pole center side arranged in the positions at angles of θ and 3θ with respect to the center of the winding slot in the circumferential direction of the rotor. In this case, the positions of the supplemental grooves become more appropriate, so that the cogging torque can be further reduced. With this appropriate arrangement, the cogging torque can be effectively suppressed.

In the motor of the second aspect, the two supplemental grooves may have their end portions on the winding slot side arranged respectively in the positions at angles of θ and 3θ with respect to the center of the winding slot in the circumferential direction of the rotor. Also in this case, the positions of the supplemental grooves become more appropriate, so that the cogging torque can be further reduced. With this appropriate arrangement, the cogging torque can be effectively suppressed.

In each of the aforementioned motors, it is preferred that the permanent magnet rotor is skewed within a range of not smaller than 0.4 time to not greater than one time the slot pitch γ of the salient pole section of the stator field core. In this case, the torque pulsation is reduced by the skew structure.

In this case, it is further preferred that the permanent magnet rotor is skewed by 5/6 times the slot pitch γ of the salient pole section of the stator field core. In this case, the induction voltage of the motor can be made to have a trapezoidal waveform. By thus making the induction voltage of the motor have a trapezoidal waveform, a torque ripple occurring in the electrifying stage can be suppressed.

Furthermore, it is also preferred that the permanent magnet rotor is skewed by 0.5 time the slot pitch γ of the salient pole section of the stator field core. In this case, the induction voltage of the motor can be made to have a sine waveform. By thus making the induction voltage of the motor have a sine waveform, a torque ripple occurring in the electrifying stage can be suppressed.

Furthermore, the permanent magnet rotor may be skewed by 0.47 time the slot pitch γ of the salient pole section of the stator field core. In this case, the induction voltage of the motor can be made to have a sine waveform. By thus making the induction voltage of the motor have a sine waveform, a torque ripple occurring in the electrifying stage can be suppressed.

In each of the aforementioned motors, it is preferred that a width α of the winding slot of the stator field core and a width β of the supplemental groove, which are facing the rotor, are set within a range of $0.5\alpha < \beta < 1.5\alpha$. In this case, the cogging torque can be reduced and the shape of the stator field core can be freely

formed. Consequently, the cogging torque can be suppressed and the motor can be easily manufactured.

Furthermore, the width α of the winding slot of the stator field core and the width β of the supplemental groove, which are facing the permanent magnet rotor, may be set so that $\alpha = \beta$. In this case, the width of the winding slot becomes appropriate, so that the cogging torque can be further reduced. Eventually, the cogging torque can be suppressed and the motor can be easily manufactured.

In each of the aforementioned motors, assuming that the radius of the stator field core surface facing the permanent magnet rotor is r, then it is preferred that a width Wt of the salient pole section of the stator field core is set so that $Wt > 3 \cdot r \cdot \cos\theta$. In this case, the torque of the motor is increased, so that the cogging torque can be further reduced. Eventually, a motor of which the torque is great and the cogging is reduced can be provided.

Furthermore, in each of the aforementioned motors, it is preferred that a minimum width Wy of the salient pole section of a yoke section between salient pole sections of the permanent magnet stator field core and a width Wt of the salient pole section are set so that $2 \cdot Wy \geq Wt$. In this case, the magnetic flux of the iron core smoothly flows, so that the torque of the motor is increased.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a view showing the structure of a permanent magnet motor according to a first embodiment of the present invention;

Fig. 2 is an enlarged view of the essential part of the permanent magnet motor shown in Fig. 1;

Fig. 3 is a chart for explaining the principle that no cogging torque is generated in the permanent magnet motor shown in Fig. 1;

Fig. 4A is a view showing the structure of a permanent magnet motor according to a second embodiment of the present invention; Fig. 4B is a graph showing a relation between an angle of rotation and a cogging torque in the permanent magnet motor shown in Fig. 4A;

Fig. 5 is an enlarged view of the essential part of the permanent magnet motor shown in Fig. 4A;

Fig. 6 is a chart for explaining the principle that no cogging torque is generated in the permanent magnet motor shown in Fig. 4A;

Fig. 7 is a view for explaining a skew angle according to the present invention;

Fig. 8 is a graph showing the variation characteristic of a line induction voltage in a case where the skew angle of the present invention is varied in a variety of ways;

Fig. 9 is a chart for explaining the principle that no cogging torque is generated in a permanent magnet motor according to a third embodiment of the present invention;

Fig. 10A is a view showing the structure of one permanent magnet motor of the third embodiment of the present invention; Fig. 10B is a graph showing a relation between an angle of rotation and a cogging torque in the permanent magnet motor shown in Fig. 10A;

Fig. 11A is a view showing the structure of another permanent magnet motor of the third embodiment of the present invention; Fig. 11B is a graph showing a relation between an angle of rotation and a cogging torque in the permanent magnet motor shown in Fig. 11A;

Fig. 12A is a view showing the structure of another permanent magnet motor of the third embodiment of the present invention; Fig. 12B is a graph showing a relation between an angle of rotation and a cogging torque in the permanent magnet motor shown in Fig. 12A;

Fig. 13A is a view showing the structure of another permanent magnet motor of the third embodiment of the present invention; Fig. 13B is a graph showing a relation between an angle of rotation and a cogging torque in the permanent magnet motor shown in Fig. 13A;

Fig. 14A is a view showing the structure of another permanent magnet motor of the third embodiment of the present invention; Fig. 14B is a graph showing a relation between an angle of rotation and a cogging torque in the permanent magnet motor shown in Fig. 14A;

Fig. 15A is a view showing the structure of another permanent magnet motor of the third embodiment of the present invention; Fig. 15B is a graph showing a relation between an angle of rotation and a cogging torque in the permanent magnet motor shown in Fig. 15A;

Fig. 16 is a view showing the structure of a permanent magnet motor according to a fourth embodiment of the present invention;

Fig. 17 is an enlarged view of the essential part of the permanent magnet motor shown in Fig. 16;

Fig. 18 is a chart for explaining the principle that no cogging torque is generated in the permanent magnet motor shown in Fig. 16;

Fig. 19 is a chart for explaining the effect of a modification example of the permanent magnet motor shown in Fig. 16;

Fig. 20 is a view showing the structure of a permanent magnet motor according to a fifth embodiment of the present invention;

Fig. 21 is an enlarged view of the essential part of the permanent magnet motor shown in Fig. 20;

Fig. 22 is a view for explaining the effect of a modification example of the permanent magnet motor shown in Fig. 20;

Fig. 23A is a view showing the structure of a prior art permanent magnet motor; Fig. 23B is a graph

showing a relation between an angle of rotation and a cogging torque in the permanent magnet motor shown in Fig. 23A; and

Fig. 24 is an enlarged view of the essential part of the permanent magnet motor shown in Fig. 23A.

BEST MODE FOR CARRYING OUT THE INVENTION

(First Embodiment)

Fig. 1 is a sectional view of a permanent magnet motor of a 6-pole 9-slot type, while Fig. 2 is an enlarged view of the essential part of this motor. As shown in Fig. 1, this motor is provided with a stator in which nine stator field cores 11 are assembled into a circular arc shape. Each of the stator field cores 11 is provided with a salient pole section 11a which is formed so as to protrude toward the center side of the motor. In this case, a rotor 12 (permanent magnet rotor) is arranged in a space inside the ring-shaped stator, where six permanent magnet magnetic poles 13 are fixed in a circular arc shape on the peripheral portion of this rotor 12. A winding is wound around a winding slot 17 provided between adjacent two stator field cores 11. When a current is made to flow through this winding, the rotor 12 rotates to drive the motor.

As shown in Fig. 2, an angle θ between a straight line which extends through the center of the rotor 12 (rotor center) and a contact surface of adjacent two stator field cores 11 and a straight line which extends through the rotor center and a tip corner portion of the salient pole section 11a is referred to as a "slot angle θ" of the salient pole section 11a. It is to be noted that the term "angle" means the central angle of the rotor 12 when singly used. As is apparent from Fig. 2, an angle of the permanent magnet magnetic pole 13 with respect to the length (circular arc portion) in the rotor circumference direction is set to 6θ, an angle of the stator field core 11 with respect to the length in the rotor circumference direction is set to 4θ, and an angle of a tip portion of the salient pole section 11a with respect to the length in the rotor circumference direction is set to 2θ.

Fig. 3 shows a relative positional relation between the permanent magnet magnetic pole 13 and the salient pole section 11a of the stator field core 11. In the graph of a slot function shown in Fig. 3, the function value of the winding slot 17 is defined as one, and the function value of the stator field cores 11 is defined as zero. In the graph of the stator field cores (A) through (C) are shown forces F exerted on the stator field cores 11. An attracting force is exerted between the stator field cores 11 and the permanent magnet magnetic poles 13, and the rotor 12 is rotated by this attracting force. A cogging torque is generated due to an unbalance of a component force in the circumferential direction of this attracting force.

A force exerted on a pair of magnetic poles will be described below with a force in the rotor circumference direction expressed by Fx with reference to Fig. 3. In regard to the iron core 11a and an iron core 11c of the stator field core (A), a force $-Fx_1$ and a force Fx_1 in the rotor circumference direction are balanced with each other, and a force Fx_2 and a force $-Fx_2$ in the rotor circumference direction are balanced with each other. Further, in regard to an iron core 11b, a force $-Fx_3$ and a force Fx_3 in the rotor circumference direction are balanced with each other. Therefore, the force in the rotor circumference direction, i.e., the cogging torque is not generated in the stator field core (A).

When the stator field core 11 and the permanent magnet rotor 12 rotate relatively to each other to enter into a state of a stator field core (B), a force $-Fx_4$ and a force Fx_4 in the rotor circumference direction are balanced with each other in regard to an iron core 11d and an iron core 11e. In regard to the iron core 11d and an iron core 11f, a force Fx_5 and a force $-Fx_5$ in the rotor circumference direction are balanced with each other. In regard to the iron core 11e and the iron core 11f, a force $-Fx_6$ and a force Fx_6 in the circumferential direction are balanced with each other. Therefore, the force in the circumferential direction, i.e., the cogging torque is not generated.

When this is considered in terms of the slot function, a negative force is exerted in the rotor circumference direction at a point where the slot function changes from one to zero, while a positive force is exerted in the rotor circumference direction at a point where the slot function changes from zero to one. Therefore, if the slot function on the north pole side and the slot function on the south pole side are identical to each other when the function value of the slot function on the south pole side is changed from zero to one with the slot function on the north pole side fixed, no force is consequently generated in the circumferential direction. Therefore, in an attempt at generating such an effect in this motor, assuming that P is an integer not smaller than one, then the number of the permanent magnet magnetic poles 13 (magnetic pole count) of the rotor 12 is set to 2P and the number of the salient pole sections 11a (salient pole count) of the stator field core 11 is set to 3P. Assuming that N is an odd number not smaller than three, then the slot angle of the salient pole section 11a of the stator field core 11 is set to 1/N of the angle corresponding to the length in the rotor circumference direction of the permanent magnet magnetic pole 13.

Although the construction of the motor of the 6-pole 9-slot type motor is shown in this first embodiment, the present invention is not limited to such a motor, and it is a matter of course that it can be similarly applied to, for example, motors of a 4-pole 6-slot type, an 8-pole 12-slot type, a 10-pole 15-slot type and the like.

Although this first embodiment employs the permanent magnet magnetic poles 13 as the magnetic poles of the rotor 12, the magnetic poles are not always required to be permanent magnets, and it may be a one which has its surface covered with a resin or iron and is

internally provided with a permanent magnet or a one in which a magnetic pole is formed by flowing a current by a winding.

(Second Embodiment)

Fig. 4A shows a sectional view of a permanent magnet motor of a 6-pole 9-slot type provided with a supplemental groove positioned in portions which belong to the tip portion of the salient pole section and are separated from the center of the winding slot by an angle of 10° and 30° in the circumferential direction. Fig. 5 shows an enlarged view of the essential part of this motor.

As shown in Fig. 4A, this motor is provided with a stator in which nine stator field cores 21 are assembled into a circular arc shape. Each of the stator field cores 21 (stator) is provided with a salient pole section 21a which is formed so as to protrude toward the center side (rotor center side) of the motor. A rotor 22 (permanent magnet rotor) is arranged in a space inside the ring-shaped stator, and six permanent magnet magnetic poles 23 are fixed in a circular arc shape on the peripheral portion of this rotor 22. A winding is wound around a winding slot 27 provided between adjacent two stator field cores 21. When a current is made to flow through this winding, the rotor 22 rotates to drive the motor. A tip portion of each salient pole section 21a, i.e., its surface facing the rotor 22 (permanent magnet magnetic pole 23) is provided with two supplemental grooves 24.

As shown in Fig. 5, the slot angle θ of the salient pole section 21a is defined as an angle between a straight line which extends through the center (rotor center) of the rotor 22 and the center of the supplemental groove 24 and a straight line which extends through the rotor center and the center of the winding slot 27 of the stator field cores 21. In this motor, an angle of the permanent magnet magnetic pole 23 of the rotor 22 with respect to the length (circular arc portion) in the rotor circumference direction is set to 6θ, an angle of the stator field core 21 with respect to the length in the rotor circumference direction is set to 4θ, and an angle corresponding to an interval in the rotor circumference direction between both the supplemental grooves 24 of the salient pole section 21a is set to 2θ.

Fig. 6 shows a relative positional relation between the permanent magnet magnetic pole 23 and the salient pole section 21a of the stator field core 21. If the slot function and the fundamental wave of the slot function shown in Fig. 6 are combined with each other, a slot function which causes almost no cogging torque as shown in Fig. 4B can be obtained. That is, by providing the salient pole section 21a of the stator field core 21 with the supplemental grooves 24, the fundamental wave component of the cogging torque can be removed, and accordingly the cogging torque which is actually generated is only the higher harmonic component of the slot function. As described above, in the motor of this second embodiment, the cogging torque is reduced by virtue of the provision of the supplemental grooves 24.

In this motor, assuming that P is an integer not smaller than one, then the number of the permanent magnet magnetic poles 23 (magnetic pole count) of the rotor 22 is set to 2P and the number of the salient pole sections 21a (salient pole count) of the stator field core 21 is set to 3P. As stated before, the salient pole sections 21a of the stator field cores 21 are each provided with two supplemental grooves 24. Assuming that an angle between the magnetic poles is 4θ, then the centers of the two supplemental grooves 24 are arranged in a position at an angle θ and a position at an angle 3θ with respect to the center of the winding slot 27 when viewed in the rotor circumference direction.

In the motor of the second embodiment, a width β of the supplemental groove 24 in the rotor circumference direction is set within a range of not smaller than 0.5 time to not greater than 1.5 times the width α of the winding slot 27 in the rotor circumference direction. With this arrangement, an effect of cancelling the fundamental wave of the cogging torque by the supplemental grooves 24 is improved, so that the cogging torque is further reduced. In this case, it is specifically preferable to set the width α of the winding slot 27 equal to the width β of the supplemental groove 24, namely satisfying $\alpha = \beta$.

When driving this permanent magnet motor by a sine wave, the torque pulsation can be further reduced by skewing (giving a bias to) the permanent magnet magnetic pole 23 by one half of a slot pitch γ, or by making the skew angle one half of the slot pitch γ.

Fig. 7 is a view for explaining the skew angle, and ϕ represents the skew angle and γ represents the slot pitch in Fig. 7.

Fig. 8 is a graph showing line induction voltage waveforms when the skew angle is varied. When a rectangular wave drive is used as a control system of the permanent magnet motor, no torque pulsation is generated so long as a torque pulsation characteristic (corresponding to the line induction voltage waveform) owned by the permanent magnet motor is flat in a control position corresponding to the flat portion of the rectangular wave. The line induction voltage waveform, which also varies depending on the drive electrification system of the rectangular wave, becomes a trapezoidal wave as the skew angle is increased as is apparent from Fig. 8, when an effect that the torque pulsation is reduced and the cogging torque is reduced is generated. As stated before, in the motor of the second embodiment, the magnetic pole count of the rotor 22 is set to 2P (P is an integer not smaller than one) and the salient pole count of the stator field cores 21 is set to 3P. When the rectangular wave drive of a 120°-electrification system is used as the control system, it is preferable to make the permanent magnet rotor 22 have a structure in which it is skewed within a range of not smaller than 0.4 time to not

greater than one time the slot pitch of the stator field cores 21. It is specifically preferable to make 5/6 times the skew.

By performing such a skew on the permanent magnet motor whose cogging torque is reduced by the supplemental grooves 24, the cogging torque can be further reduced.

Although the motor of this second embodiment employs the permanent magnet magnetic poles 23 as the magnetic poles of the rotor 22, the magnetic poles are not limited to the permanent magnets. For example, it may be a one which has its surface covered with a resin or iron and is internally provided with a permanent magnet or a one in which a magnetic pole is formed by flowing a current by a winding.

(Third Embodiment)

In a motor of this third embodiment, each salient pole section is provided with three or more supplemental grooves as shown in, for example, Fig. 10A.

Fig. 9 shows a relative positional relation between the permanent magnet magnetic pole 33 and the salient pole section 31a of the stator field core 31 provided with supplemental grooves 34. Then, in the graph of the slot function in Fig. 9, the slot function value is defined as one in regard to the winding slot, and the slot function value is defined as zero in regard to the iron core. Eventually, if the slot function is drawn and the fundamental wave of the slot function is drawn, a slot function having no cogging torque as shown in Fig. 6 results.

That is, by providing the salient pole section 31a of this stator field core 31 with the supplemental grooves 34 and 35 as shown in Fig. 9, the fundamental wave component of the cogging torque can be removed. In this case, the cogging torque which is actually generated is the higher harmonic component due to the slot functions of the supplemental grooves 34 and the supplemental groove 35, generating an effect that the cogging torque is reduced. In the motor of this third embodiment, assuming that P is an integer not smaller than one, then the magnetic pole count of the rotor 32 (permanent magnet rotor) is set to 2P and the salient pole count of the stator field cores 31 is set to 3P. Then, the salient pole section 31a of each stator field core 31 is provided with three or more supplemental grooves 34 and 35. In this case, assuming that an angle corresponding to the length in the rotor circumference direction of the stator field core 31 is 4θ, then the centers of the two supplemental grooves among the supplemental grooves provided at the salient pole section 31a of the stator field core 31 are arranged in positions at angles of θ and 3θ with respect to the center of the winding slot when viewed in the rotor circumference direction, and the other supplemental grooves are each arranged in an arbitrary position.

In the motor of the third embodiment, the width β in the rotor circumference direction of the supplemental groove 34 is set within a range of not smaller than 0.5 time to not greater than 1.5 times the width α in the rotor circumference direction of the winding slot 37 of the stator field cores 31 facing the rotor 32. With this arrangement, an effect of cancelling the fundamental wave of the cogging torque by the supplemental grooves 34 is improved, so that the cogging torque is further reduced. In this case, it is specifically preferable to set the width α of the winding slot 37 equal to the width β of the supplemental grooves 34, namely satisfying $\alpha = \beta$.

When driving this permanent magnet motor by a sine wave, the torque pulsation can be further reduced by skewing the permanent magnet magnetic pole 33 by one half of the slot pitch, or by making the skew angle one half of the slot pitch.

A variety of preferable configurations of the supplemental groove in the motor of this third embodiment can be considered, and a representative configuration of the supplemental groove will be described below.

In a motor of the 6-pole 9-slot type shown in Fig. 10A, the salient pole section 31a of each stator field core 31 is provided with three supplemental grooves 34, 35a and 34 for the purpose of reducing the cogging torque, and the supplemental grooves are arranged in positions at angles of 10°, 20° and 30°, respectively, with respect to the winding slot center. The supplemental groove 35a arranged in the middle of the three supplemental grooves 34, 35a and 34 of the salient pole section 31a is positioned at the center of the salient pole section 31a when viewed in the rotor circumference direction. Fig. 10B shows a variation characteristic of the cogging torque of the motor shown in Fig. 10A with respect to the angle of rotation.

In a motor of the 6-pole 9-slot type shown in Fig. 11A, the salient pole section 31a of each stator field core 31 is provided with four supplemental grooves 35c, 34, 34 and 35c for the purpose of reducing the cogging torque, and the supplemental grooves are arranged in positions at angles of 5°, 10°, 30° and 35°, respectively, with respect to the winding slot center. Fig. 11B shows a variation characteristic of the cogging torque of the motor shown in Fig. 11A with respect to the angle of rotation.

In a motor of the 6-pole 9-slot type shown in Fig. 12A, the salient pole section 31a of each stator field core 31 is provided with five supplemental grooves 34, 35a, 35b, 35a and 34 for the purpose of reducing the cogging torque, and the supplemental grooves are arranged in positions at angles of 10°, 15°, 20°, 25° and 30°, respectively, with respect to the winding slot center. Fig. 12B shows a variation characteristic of the cogging torque of the motor shown in Fig. 12A with respect to the angle of rotation.

In a motor of the 6-pole 9-slot type shown in Fig. 13A, the salient pole section 31a of each stator field core 31 is provided with five supplemental grooves 35c, 34, 35a, 34 and 35c for the purpose of reducing the cogging torque, and the supplemental grooves are

arranged in positions at angles of 5°, 10°, 20°, 30° and 35°, respectively, with respect to the winding slot center. Fig. 13B shows a variation characteristic of the cogging torque of the motor shown in Fig. 13A with respect to the angle of rotation.

In a motor of the 6-pole 9-slot type shown in Fig. 14A, the salient pole section 31a of each stator field core 31 is provided with six supplemental grooves 35c, 34, 35b, 35b, 34 and 35c for the purpose of reducing the cogging torque, and the supplemental grooves are arranged in positions at angles of 5°, 10°, 15°, 25°, 30° and 35°, respectively, with respect to the winding slot center. Fig. 14B shows a variation characteristic of the cogging torque of the motor shown in Fig. 14A with respect to the angle of rotation.

In a motor of the 6-pole 9-slot type shown in Fig. 15A, the salient pole section 31a of each stator field core 31 is provided with seven supplemental grooves 35c, 34, 35b, 35a, 35b, 34 and 35c for the purpose of reducing the cogging torque, and the supplemental grooves are arranged in positions at angles of 5°, 10°, 15°, 20°, 25°, 30° and 35°, respectively, with respect to the winding slot center. Fig. 15B shows a variation characteristic of the cogging torque of the motor shown in Fig. 15A with respect to the angle of rotation.

(Fourth Embodiment)

Fig. 16 is a sectional view of a permanent magnet motor of an 8-pole 12-slot type according to a fourth embodiment of the present invention. Fig. 17 is an enlarged view of the essential part of the motor shown in Fig. 16.

As shown in Fig. 16 and Fig. 17, in this motor, a salient pole section 41b of each stator field core 41 is provided with two supplemental grooves 44a for the purpose of reducing the cogging torque, and these two supplemental grooves 44a are arranged so that the end portion on the salient pole magnetic pole center side is positioned at angles of 7.5° and 22.5°, respectively, with respect to the winding slot center when viewed in the rotor circumference direction.

This motor is provided with a stator in which twelve stator field cores 41 are assembled into a circular arc shape or a semicylindrical shape. Then, each stator field core 41 (stator) is provided with a salient pole section 41b which is formed so as to protrude toward the center side (rotor center side) of the motor. A rotor 42 (permanent magnet rotor) is arranged in a space inside the ring-shaped stator, and eight permanent magnet magnetic poles 43 are fixed in a circular arc shape on the peripheral portion of this rotor 42. A winding is wound around a winding slot 47 provided between adjacent two stator field cores 41. When a current is made to flow through this winding, the rotor 42 rotates to drive the motor. A tip portion of each salient pole section 41b, i.e., its surface (opposite surface) facing the rotor 42 (permanent magnet magnetic pole 43) is provided with two supplemental grooves 44a.

Then, in this motor, as is apparent from Fig. 17, the slot angle θ of the salient pole section 41b is defined as an angle between a straight line which extends through the center (rotor center) of the rotor 42 and an end portion on the salient pole section center side of the supplemental groove 44a and a straight line which extends through the rotor center and the center of the winding slot 47 of the stator field cores 41. In this motor, an angle of the rotor 42 with respect to the length (circumference arc portion) in the rotor circumference direction of each permanent magnet magnetic pole 43 is set to 6θ, an angle of the stator field core 41 with respect to the length in the rotor circumference direction is set to 4θ, and an angle corresponding to an interval (salient pole magnetic pole interval) in the rotor circumference direction between both the salient pole section center side end portions of both the supplemental grooves 44a of the salient pole section 41b is set to 2θ.

Fig. 18 shows a principle in removing the greatest fundamental wave component when the cogging torque component is subjected to a higher harmonic analysis. Fig. 18 also shows a force F exerted on the stator field cores (A), (B) and (C) when the permanent magnet magnetic pole 43 and the stator field core 41 are changed in position in a permanent magnet motor in which the permanent magnet magnetic pole 43, the salient pole section 41b of the stator field core 41 and a winding slot 47 are arranged in a relative angular relation of 3θ : θ : θ.

In the graph of the slot function shown in Fig. 18, the function value is defined as one in regard to the slot (winding slot 47), and the function value is defined as zero in regard to the iron core (stator field core 41). In the graph of the stator field cores (A) through (C) is shown a force F exerted on the stator field core 41. In this case, an attracting force is exerted between the stator field core 41 and the permanent magnet magnetic pole 43, and the rotor 42 is rotated by this attracting force. A cogging torque is generated due to an unbalance of the component force in the circumferential direction of this attracting force.

A force exerted on a pair of magnetic poles will be described below with the force in the rotor circumference direction expressed by Fx with reference to Fig. 18. In regard to the iron core 41a and the iron core 41c of the stator field core (A), a force $-Fx_1$ and a force Fx_1 in the rotor circumference direction are balanced with each other, and a force Fx_2 and a force $-Fx_2$ in the rotor circumference direction are balanced with each other. In regard to an iron core 41b, a force $-Fx_3$ and a force Fx_3 in the rotor circumference direction are balanced with each other. Therefore, the force in the rotor circumference direction, i.e., the cogging torque is not generated in the stator field core (A).

In the stator field core (B), a force $-Fx_4$ and a force Fx_4 in the rotor circumference direction are balanced with each other in regard to an iron core 41d and an iron

core 41e. In regard to the iron core 41d and an iron core 41f, a force Fx_5 and a force $-Fx_5$ in the rotor circumference direction are balanced with each other. In regard to the iron core 41e and the iron core 41f, a force $-Fx_6$ and a force Fx_6 in the rotor circumference direction are balanced with each other. Therefore, the force in the rotor circumference direction, i.e., the cogging torque is not generated.

Further, in the stator field core (C), a force $-Fx_7$ and a force Fx_7 in the rotor circumference direction are balanced with each other in regard to an iron core 41g. In regard to an iron core 41h and an iron core 41i, a force $-Fx_8$ and a force Fx_8 in the rotor circumference direction are balanced with each other, and a force Fx_9 and a force $-Fx_9$ in the rotor circumference direction are balanced with each other. Therefore, the force in the circumferential direction, i.e., the cogging torque is not generated in the stator field core (C).

When this is considered in terms of the slot function, a negative force is exerted in the rotor circumference direction at a point where the slot function changes from one to zero, while a positive force is exerted in the rotor circumference direction at a point where the slot function changes from zero to one. That is, if the slot function on the north pole side and the slot function on the south pole side are identical to each other when the zero and one of the slot function on the south pole side are exchanged with each other with the slot function on the north pole side fixed, no force is generated in the circumferential direction. With this arrangement, the fundamental wave component of the cogging torque can be removed. However, since there are few salient pole sections 41b which belong to the stator field core 41 and face the permanent magnet magnetic pole 43, and therefore, a torque exerted on the rotor 42 becomes small.

Fig. 19 shows a relative positional relation and a relation of force between the permanent magnet magnetic pole 43 and the salient pole section 41b in a motor in which a magnetic field of the permanent magnet magnetic pole 43 is effectively utilized by increasing the area of the salient pole section 41b of the stator field core 41 facing the permanent magnet magnetic pole 43 and a supplemental groove is provided for reducing the cogging torque. In this case, if its slot function G_{11} is drawn, this slot function G_{11} can be separated into a fundamental wave component G_{10} which causes no cogging torque shown in Fig. 18 and a higher harmonic component $-G_{11M}$. Therefore, the greatest fundamental wave component can be removed when the cogging torque component is subjected to a higher harmonic analysis. In this case, the cogging torque which is actually generated is the higher harmonic component of the slot function. With this groove arrangement, the cogging torque is reduced.

In the motor of this fourth embodiment, assuming that P is an integer not smaller than one, then the magnetic pole count of the rotor 42 is set to 2P and the salient pole count of the stator field cores 41 is set to 3P. Then, as stated before, the salient pole section 41b of each stator field core 41 is provided with two supplemental grooves 44a. Assuming that an angle between the salient pole magnetic poles is 4θ, then the two supplemental grooves 44a are arranged so that the end portions on the salient pole magnetic pole center side are positioned at angles of θ and 3θ with respect to the center of the winding slot 47 when viewed in the rotor circumference direction.

In the motor of the fourth embodiment, it is preferred that the width β in the circumferential direction of the supplemental groove 44a is set within a range of not smaller than 0.5 time to not greater than 1.5 times the width α in the rotor circumference direction of the winding slot 47 of the stator field cores 41 facing the rotor 42. With this arrangement, an effect of cancelling the fundamental wave of the cogging torque by the supplemental grooves 44a is improved, so that the cogging torque is further reduced. In this case, it is specifically preferable to set the width α of the winding slot 47 equal to the width β of the supplemental groove 44a, namely satisfying $\alpha = \beta$.

In this motor, assuming that the radius of the surface of the stator field core 41 facing the permanent magnet rotor 42 is r, then it is preferred that a width Wt of the salient pole section 41b of the stator field core 41 is set so that $Wt > 3 \cdot r \cdot \cos\theta$. With this arrangement, the flow of the magnetic flux in the salient pole section 41b becomes smooth, so that the distortion of the magnetic flux is reduced and the cogging torque is further reduced.

In this motor, it is preferred that a minimum width Wy of the salient pole section of a yoke section between salient pole sections of the stator field core 41 and the width Wt of the salient pole section 41b are set so that $2 \cdot Wy \geq Wt$. With this arrangement, the flow of the magnetic flux in the salient pole section 41b becomes smooth, so that the cogging torque is further reduced.

Further, when driving this permanent magnet motor by a sine wave, the torque pulsation can be further reduced by skewing the permanent magnet magnetic pole 43 by one half of the slot pitch.

When the control system of the permanent magnet motor is sine wave drive, no torque pulsation is generated if the torque pulsation characteristic owned by the permanent magnet motor is a sine wave too. In this case, it is preferable to skew the permanent magnet rotor 42 within a range of not smaller than 0.4 time to not greater than one time the slot pitch of the stator field core 41, and it is specifically preferable to skew it by 0.5 time or 0.47 time.

(Fifth Embodiment)

Fig. 20 is a sectional view of a permanent magnet motor of the 8-pole 12-slot type according to a fifth embodiment of the present invention. Fig. 21 is an

enlarged view of the essential part of the motor shown in Fig. 20.

As shown in Figs. 20 and 21, in this motor, a salient pole section 51c of each stator field core 51 is provided with two supplemental grooves 54b for the purpose of reducing the cogging torque, and these two supplemental grooves 54b are arranged so that the end portion on the winding slot side is positioned at angles of 7.5° and 22.5° with respect to the winding slot center when viewed in the rotor circumference direction.

This motor is provided with a stator in which twelve stator field cores 51 are assembled into a circular arc shape or a semicylindrical shape. Then, each stator field core 51 (stator) is provided with the salient pole section 51c which is formed so as to protrude toward the center side (rotor center side) of the motor. A rotor 52 (permanent magnet rotor) is arranged in a space inside the ring-shaped stator, and eight permanent magnet magnetic poles 53 are fixed in a circular arc shape or a semicylindrical shape on the peripheral portion of this rotor 52. A winding is wound around a winding slot 57 provided between adjacent two stator field cores 51. When a current is made to flow through this winding, the rotor 52 rotates to drive the motor. A tip portion of each salient pole section 51c, i.e., its surface (opposite surface) facing the permanent magnet rotor 52 (permanent magnet magnetic pole 53) is provided with two supplemental grooves 54b.

Then, in this motor, as is apparent from Fig. 21, the slot angle θ of the salient pole section 51c is defined as an angle between a straight line which extends through the center (rotor center) of the permanent magnet rotor 52 and an end portion on the winding slot side of the supplemental grooves 54b and a straight line which extends through the rotor center and the center of the winding slot 57 of the stator field cores 51. Then, in this motor, an angle of the permanent magnet rotor 52 with respect to the length (circumference arc portion) in the rotor circumference direction of each permanent magnet magnetic pole 53 is set to 6θ, an angle of the stator field core 51 with respect to the length in the rotor circumference direction is set to 4θ, and an angle corresponding to an interval (salient pole magnetic pole interval) in the rotor circumference direction between the winding slot side end portions of both the supplemental grooves 54b of the salient pole section 51c is set to 2θ.

Fig. 22 shows a relative positional relation and a relation of force between the permanent magnet magnetic pole 53 and the salient pole section 51c in a motor in which a magnetic field of the permanent magnet magnetic pole 53 is effectively utilized by increasing the area of the salient pole section 51c of the stator field core 51 facing the permanent magnet magnetic pole 53 and a supplemental groove is provided for reducing the cogging torque. In this case, if its slot function G_{12} is drawn, this slot function G_{12} can be separated into a fundamental wave component G_{10} which causes no cogging torque shown in Fig. 18 and higher harmonic components $-G_{12M}$ and G_{12P} Therefore, the greatest fundamental wave component can be removed when the cogging torque components are subjected to a higher harmonic analysis. In this case, the cogging torque which is actually generated is the higher harmonic component of the slot function. That is, the greatest fundamental wave component can be removed when the cogging torque component is subjected to a higher harmonic analysis, and the cogging torque which is actually generated by this becomes the higher harmonic component of the slot function. With this groove arrangement, the cogging torque is reduced.

In the motor of this fifth embodiment, assuming that P is an integer not smaller than one, then the magnetic pole count of the rotor 52 is set to 2P and the salient pole count of the stator field cores 51 is set to 3P. Then, as stated before, the salient pole section 51c of each stator field cores 51 is provided with two supplemental grooves 54b. Assuming that an angle between the salient pole magnetic poles is 4θ, then the two supplemental grooves 54b are arranged so that the end portions on the winding slot side are positioned at angles of θ and 3θ with respect to the center of the winding slot 57 when viewed in the rotor circumference direction.

In the motor of the fifth embodiment, it is preferred that the width β of the supplemental groove 54b in the rotor circumference direction is set within a range of not smaller than 0.5 time to not greater than 1.5 times the width α in the rotor circumference direction of the winding slot 57 of the stator field cores 51 facing the rotor 52. With this arrangement, an effect of cancelling the fundamental wave of the cogging torque by the supplemental grooves 54b is improved, so that the cogging torque is further reduced. In this case, it is specifically preferable to set the width α of the winding slot 57 equal to the width β of the supplemental groove 54b, namely satisfying $\alpha = \beta$.

In this motor, assuming that the radius of the surface of the stator field core 51 facing the rotor 52 is r, then it is more preferable to set the width Wt of the salient pole section 51c of the stator field core 51 so that $Wt > 3 \cdot r \cdot \cos\theta$. With this arrangement, the flow of the magnetic flux in the salient pole section 51c becomes smooth, so that the distortion of the magnetic flux is reduced and the cogging torque is further reduced.

In this motor, it is preferable to set the minimum width Wy of a yoke section between salient pole sections of the stator field core 51 and the width Wt of the salient pole section 51c so that $2 \cdot Wy \geq Wt$. With this arrangement, the flow of the magnetic flux in the salient pole section 51c becomes smooth, so that the cogging torque is further reduced.

Further, when driving this permanent magnet motor by a sine wave, the torque pulsation can be further reduced by skewing the permanent magnet magnetic pole 53 by one half of the slot pitch.

When the control system of the permanent magnet

motor is sine wave drive, no torque pulsation is generated if the torque pulsation characteristic owned by the permanent magnet motor is a sine wave too. In this case, it is preferable to skew the permanent magnet rotor 52 within a range of not smaller than 0.4 time to not greater than one time the slot pitch of the stator field core 51, and it is specifically preferable to skew it by 0.5 time or 0.47 time.

INDUSTRIAL APPLICABILITY

As described above, the motor of the present invention is useful as a permanent magnet motor and is appropriate for use in machine tools, garment manufacturing machines, robots and the like.

Claims

1. A motor characterized in that the number of magnetic poles of a rotor is set to 2P and the number of salient poles of a stator field core is set to 3P with respect to an integer P of not smaller than one, and a slot angle of the salient poles of the stator field core is set to 1/N of a magnetic pole angle with respect to an odd number N of not smaller than three.

2. A motor characterized in that the number of magnetic poles of a rotor is set to 2P and the number of salient poles of a stator field core is set to 3P with respect to an integer P of not smaller than one, each of the salient poles of the stator field core is provided with two supplemental grooves, and assuming that a salient pole magnetic interpolar angle is 4θ, then said two supplemental grooves are arranged in positions at angles of θ and 3θ with respect to a center of a winding slot in a circumferential direction of the rotor.

3. A motor as claimed in Claim 2, characterized in that said two supplemental grooves have their centers arranged respectively in the positions at angles of θ and 3θ with respect to the center of the winding slot in the circumferential direction of the rotor.

4. A motor as claimed in Claim 2, characterized in that said two supplemental grooves have their end portions on the salient pole magnetic pole center side arranged in the positions at angles of θ and 3θ with respect to the center of the winding slot in the circumferential direction of the rotor.

5. A motor as claimed in Claim 2, characterized in that said two supplemental grooves have their end portions on the winding slot side arranged in the positions at angles of θ and 3θ with respect to the center of the winding slot in the circumferential direction of the rotor.

6. A motor as claimed in Claim 1 or 2, characterized in that said rotor is slot-pitch-skewed within a range of not smaller than 0.4 time to not greater than one time of a salient pole slot of the stator field core.

7. A motor as claimed in Claim 1 or 2, characterized in that said rotor is slot-pitch-skewed by 5/6 times of a salient pole slot of the stator field core.

8. A motor as claimed in Claim 1 or 2, characterized in that said rotor is slot-pitch-skewed by 0.5 time of a salient pole slot of the stator field core.

9. A motor as claimed in Claim 1 or 2, characterized in that said rotor is slot-pitch-skewed by 0.47 time of a salient pole slot of the stator field core.

10. A motor as claimed in Claim 2, characterized in that a width α of the winding slot of the stator field core and a width β of said supplemental groove, which are facing said rotor, are set so that $0.5\alpha < \beta < 1.5\alpha$.

11. A motor as claimed in Claim 2, characterized in that a width α of the winding slot of the stator field core and a width β of said supplemental groove, which are facing said rotor, are set so that $\alpha = \beta$.

12. A motor as claimed in Claim 1 or 2, characterized in that a width Wt of the salient pole of said stator field core is set with respect to a radius r of a surface of the stator field core facing said rotor and said θ so that $Wt > 3 \cdot r \cdot \cos\theta$.

13. A motor as claimed in Claim 1 or 2, characterized in that a minimum width Wy of a salient pole section of a yoke section between the salient poles of said stator field core and a width Wt of the salient pole are set so that $2 \cdot Wy \geq Wt$.

Fig. 1

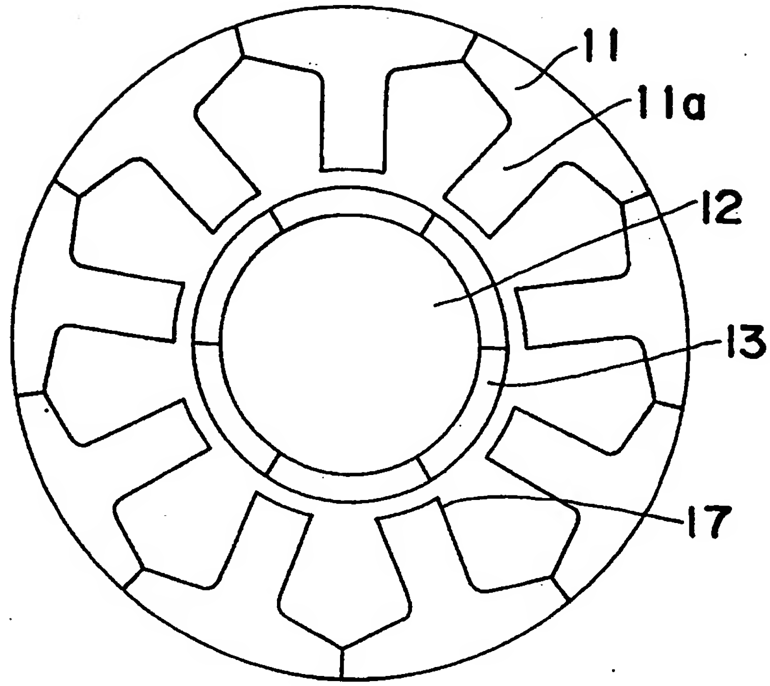


Fig. 2

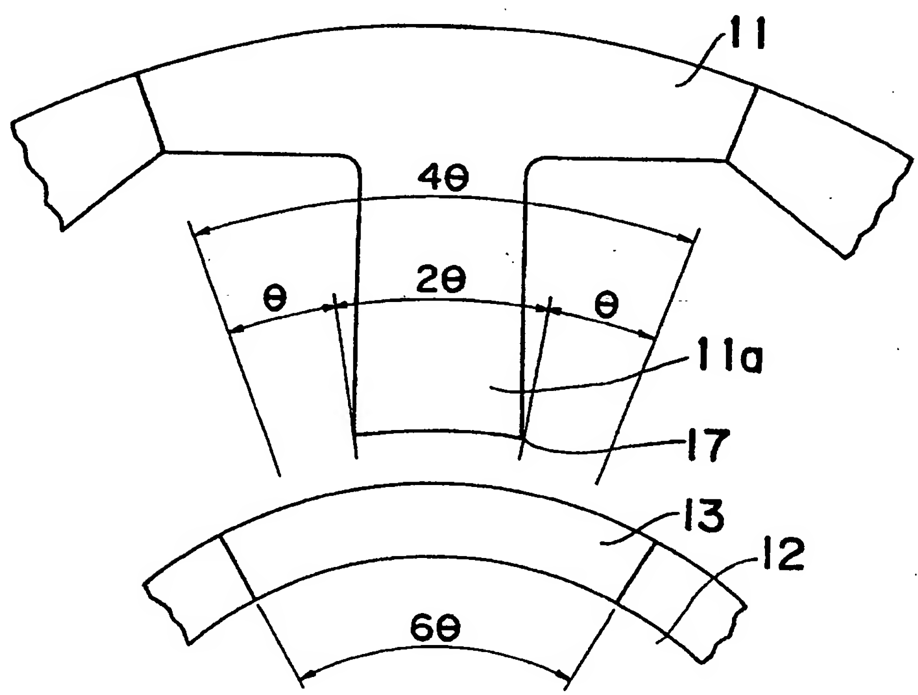


Fig.3

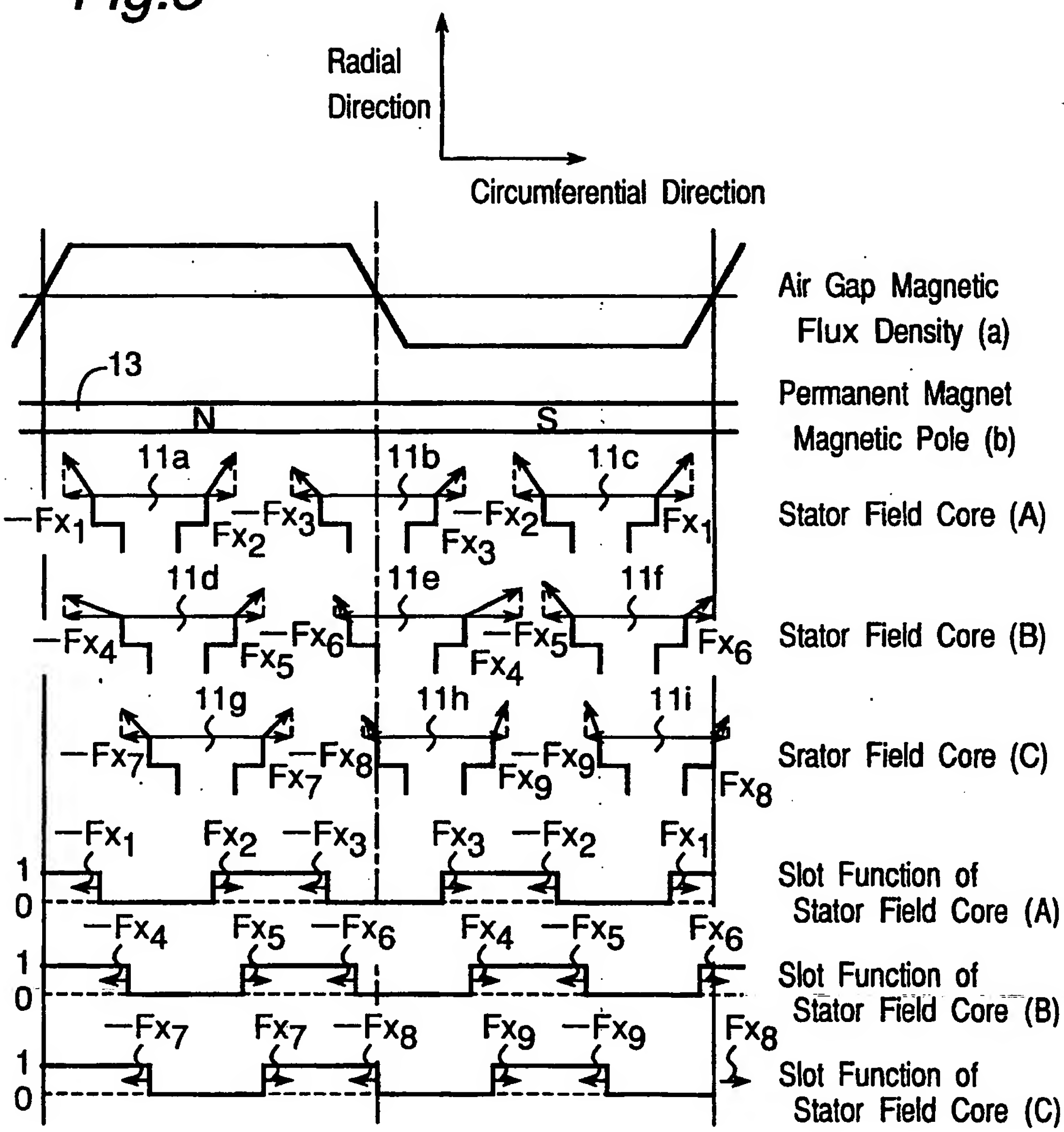

Radial Direction
Circumferential Direction
Air Gap Magnetic Flux Density (a)
13
N
S
Permanent Magnet Magnetic Pole (b)
11a
11b
11c
−Fx1
Fx2
−Fx3
Fx3
−Fx2
Fx1
Stator Field Core (A)
11d
11e
11f
−Fx4
Fx5
−Fx6
Fx4
−Fx5
Fx6
Stator Field Core (B)
11g
11h
11i
−Fx7
Fx7
−Fx8
Fx9
−Fx9
Fx8
Srator Field Core (C)
1
0
Slot Function of Stator Field Core (A)
Slot Function of Stator Field Core (B)
Slot Function of Stator Field Core (C)

Fig. 4A

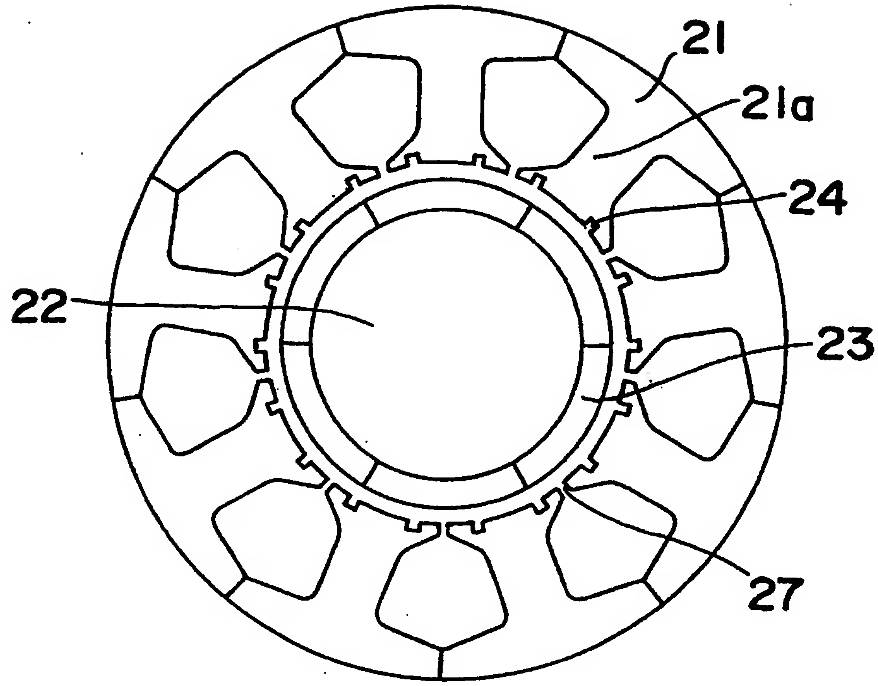

21
21a
24
22
23
27

Fig. 4B

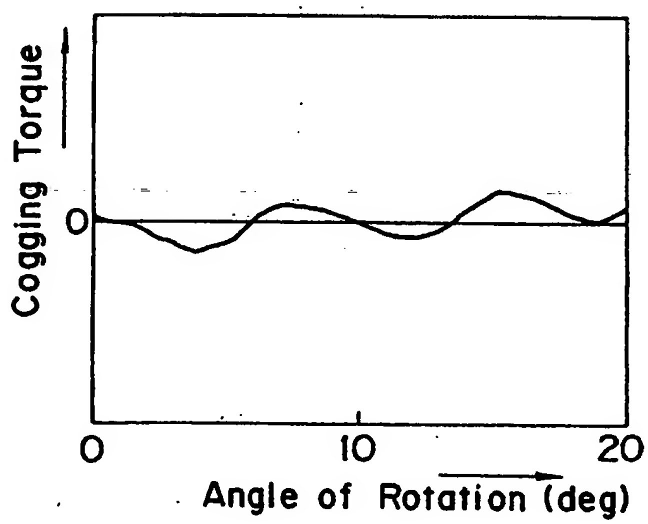

Cogging Torque
0
0
10
20
Angle of Rotation (deg)

Fig. 5

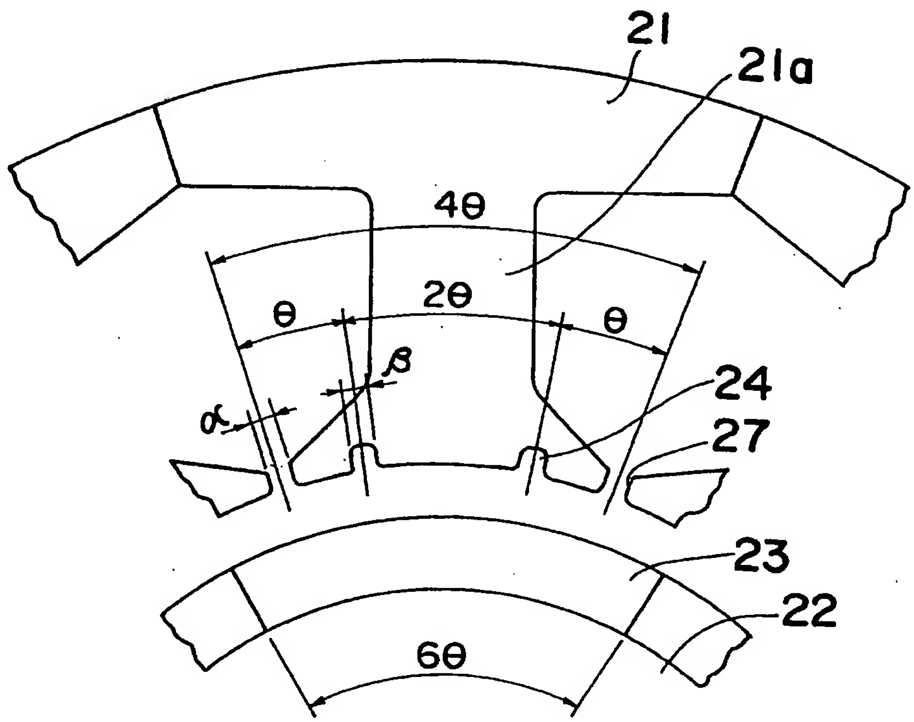


Fig.6

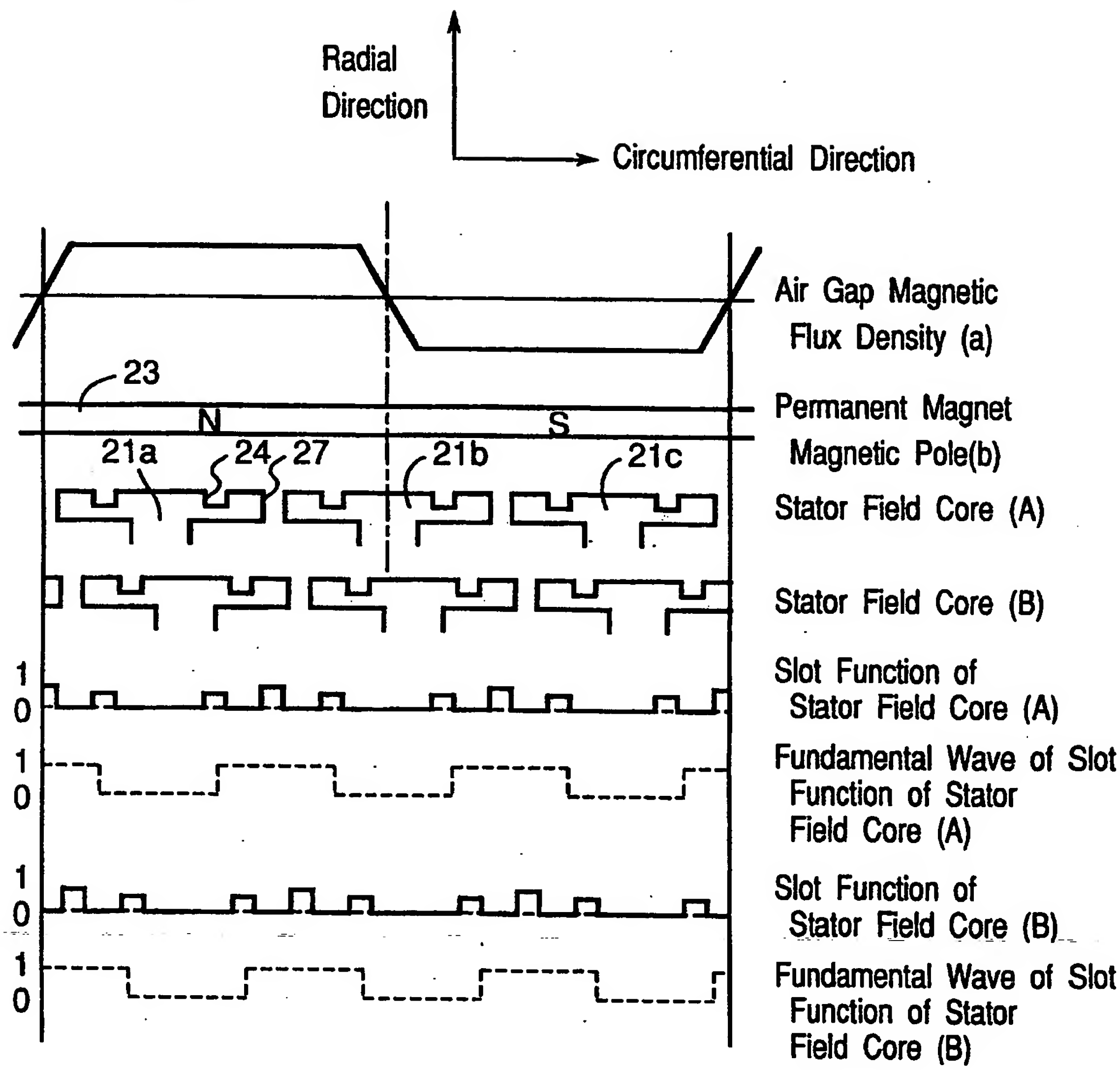

Radial
Direction
Circumferential Direction
23
N
S
21a
24
27
21b
21c
1
0
1
0
1
0
1
0
Air Gap Magnetic
Flux Density (a)
Permanent Magnet
Magnetic Pole(b)
Stator Field Core (A)
Stator Field Core (B)
Slot Function of
Stator Field Core (A)
Fundamental Wave of Slot
Function of Stator
Field Core (A)
Slot Function of
Stator Field Core (B)
Fundamental Wave of Slot
Function of Stator
Field Core (B)

Fig.7

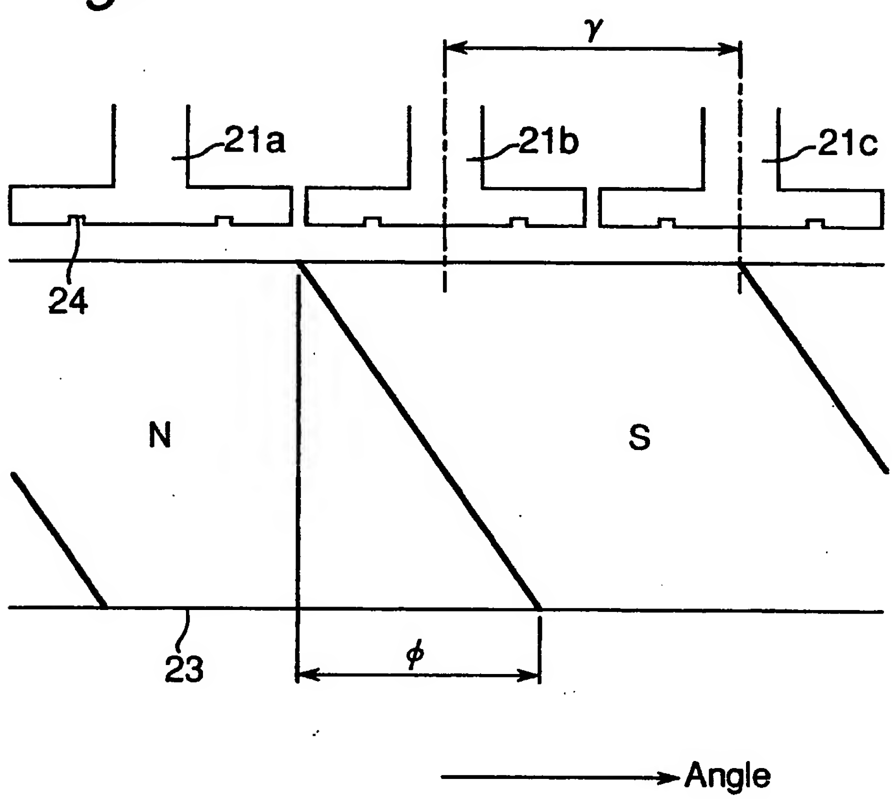


Fig. 8

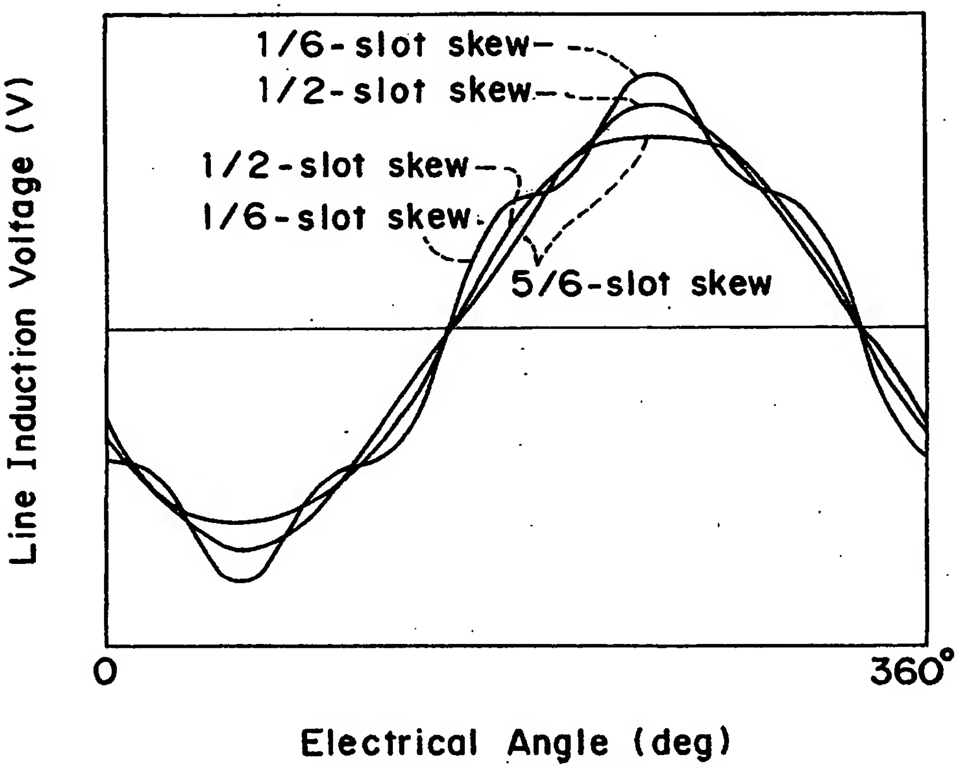

1/6-slot skew
1/2-slot skew
1/2-slot skew
1/6-slot skew
5/6-slot skew
Line Induction Voltage (V)
0
360°
Electrical Angle (deg)

Fig.9

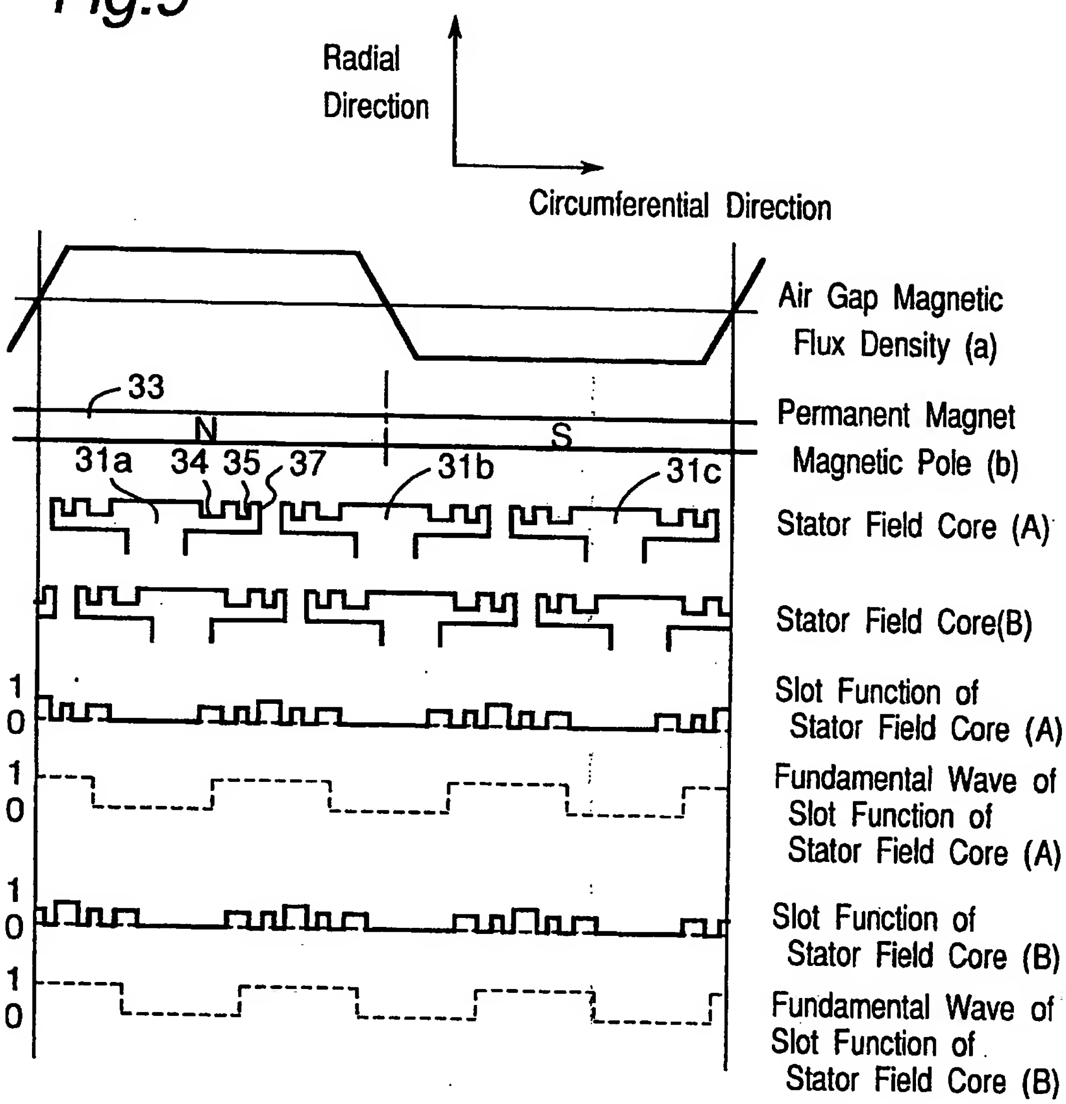

Radial Direction
Circumferential Direction
33
N
S
31a
34
35
37
31b
31c
1
0
1
0
1
0
1
0
Air Gap Magnetic Flux Density (a)
Permanent Magnet Magnetic Pole (b)
Stator Field Core (A)
Stator Field Core(B)
Slot Function of Stator Field Core (A)
Fundamental Wave of Slot Function of Stator Field Core (A)
Slot Function of Stator Field Core (B)
Fundamental Wave of Slot Function of Stator Field Core (B)

Fig. 10A

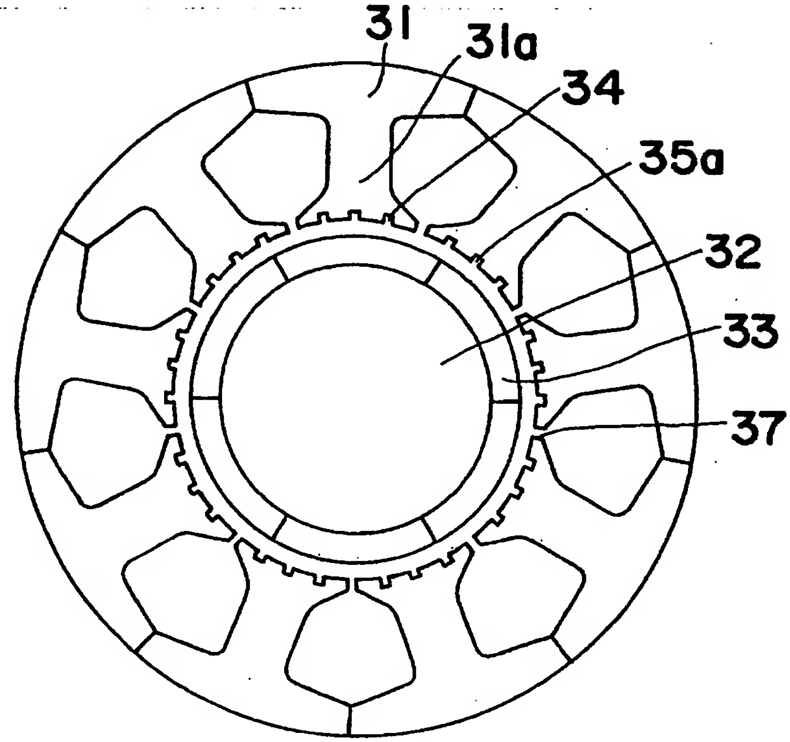


Fig. 10B

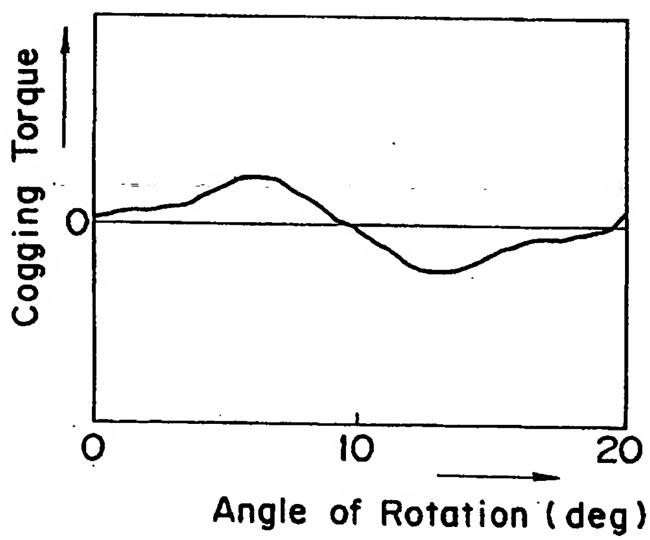


Fig. 11A

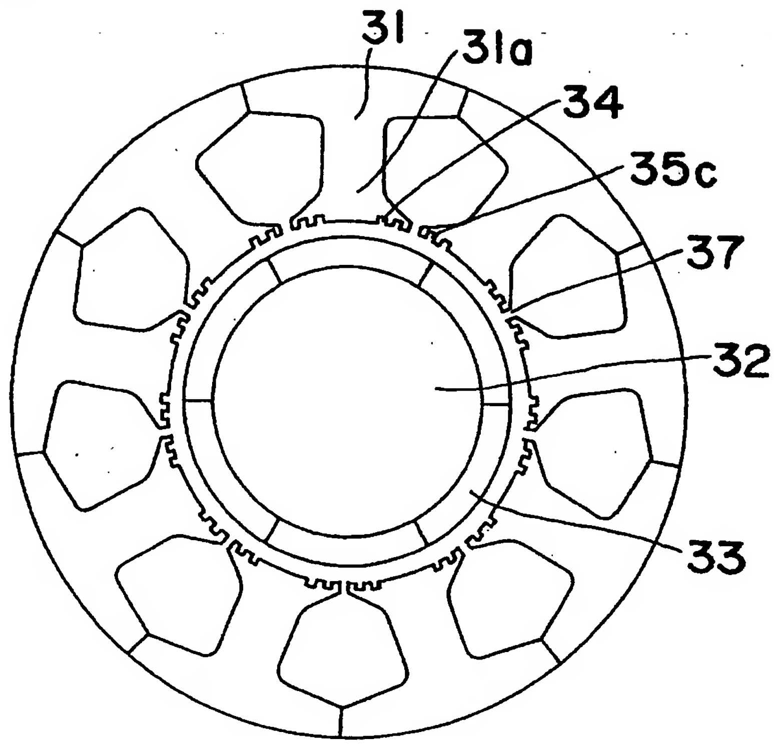


Fig. 11B

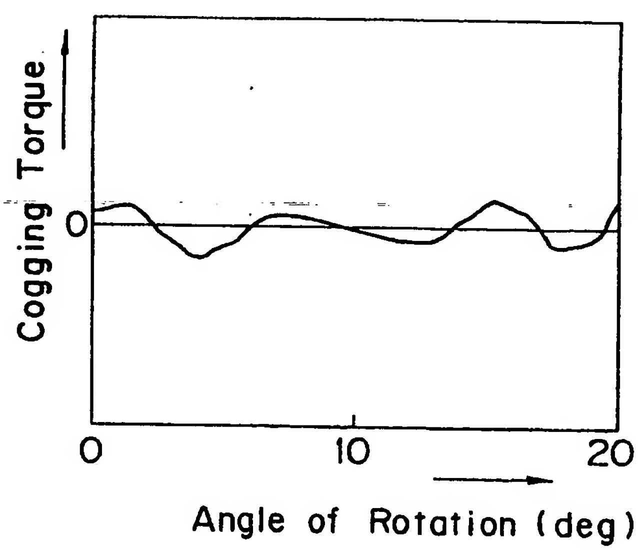


Fig. 12A

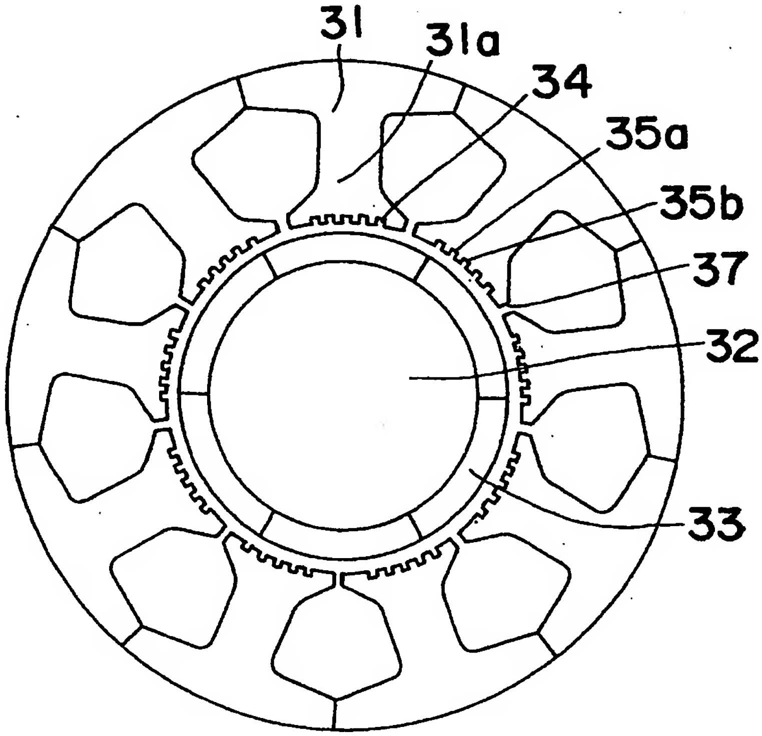


Fig. 12B

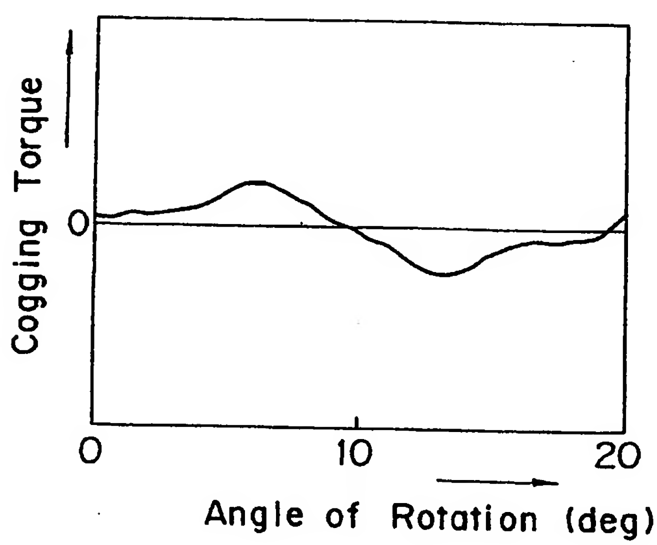


Fig. 13A

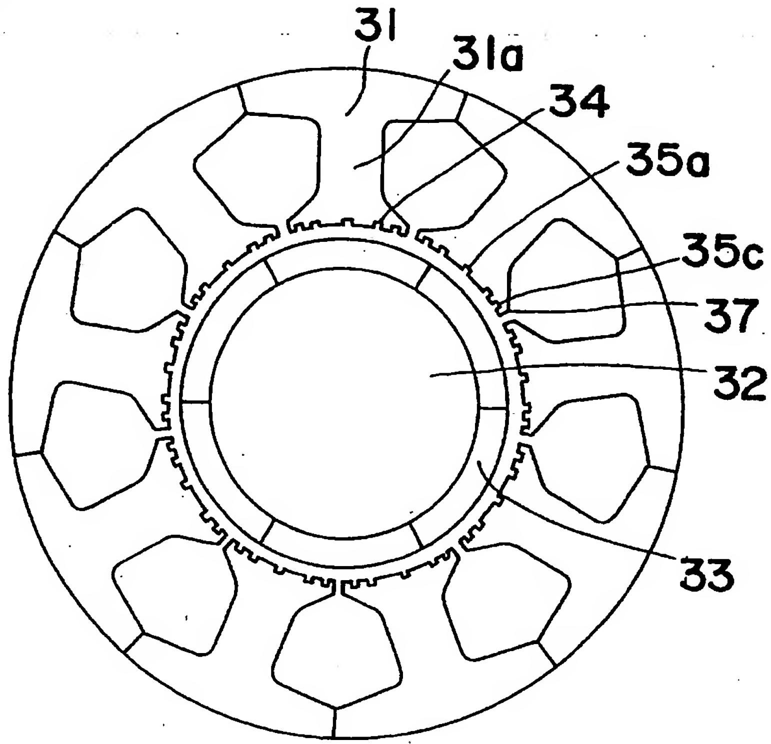


Fig. 13B

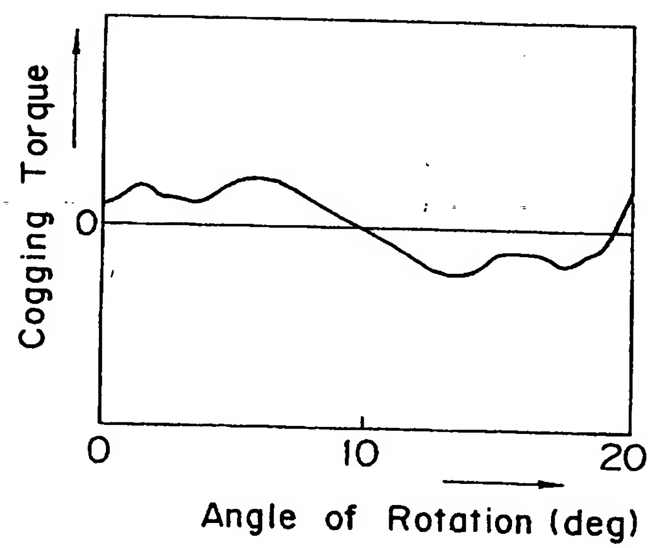


Fig. 14A

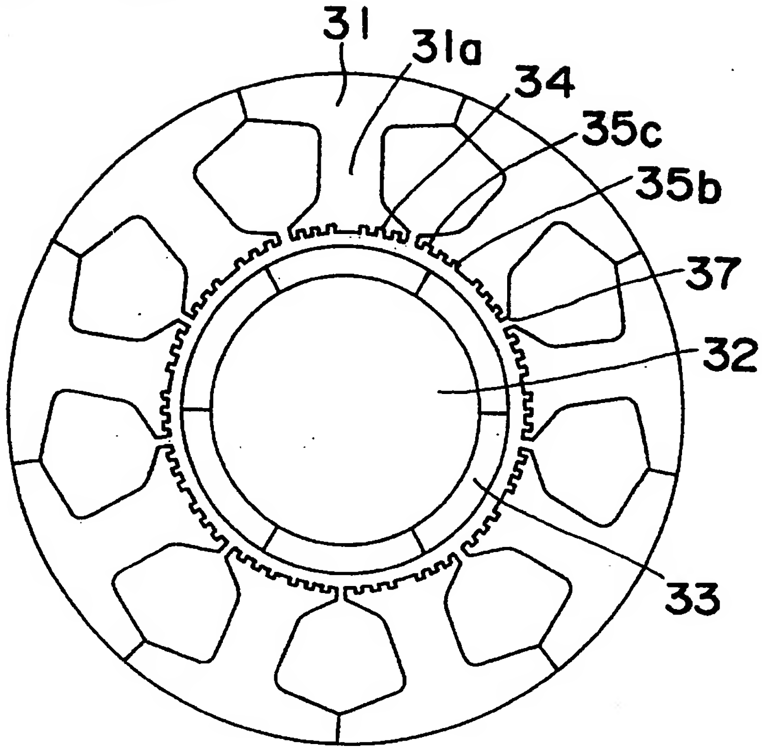


Fig. 14B

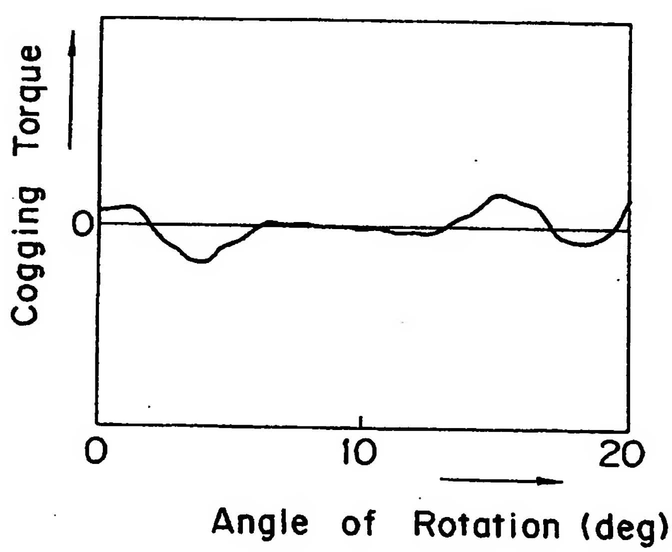


Fig.15A

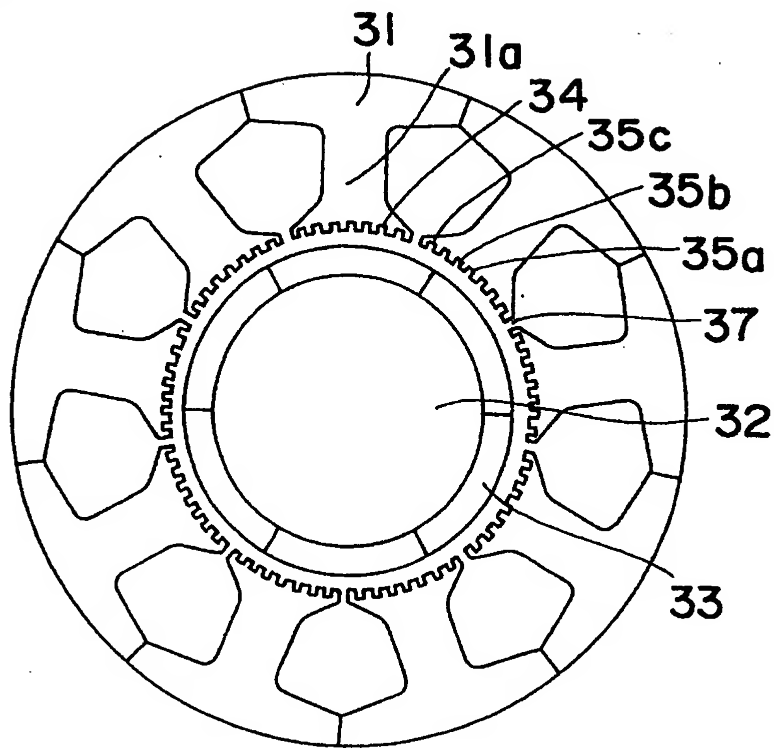


Fig.15B

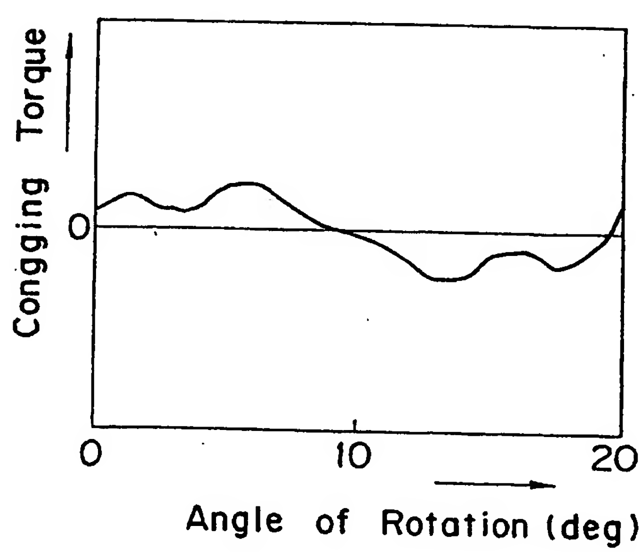


Fig. 16

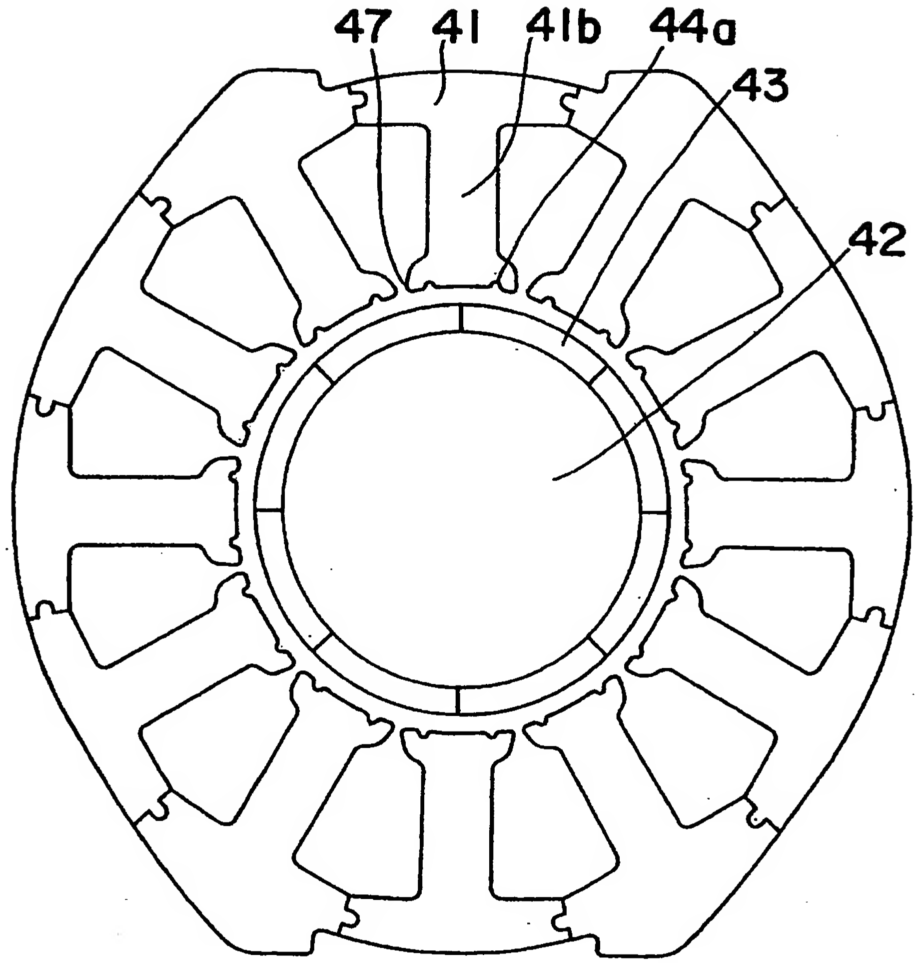


Fig. 17

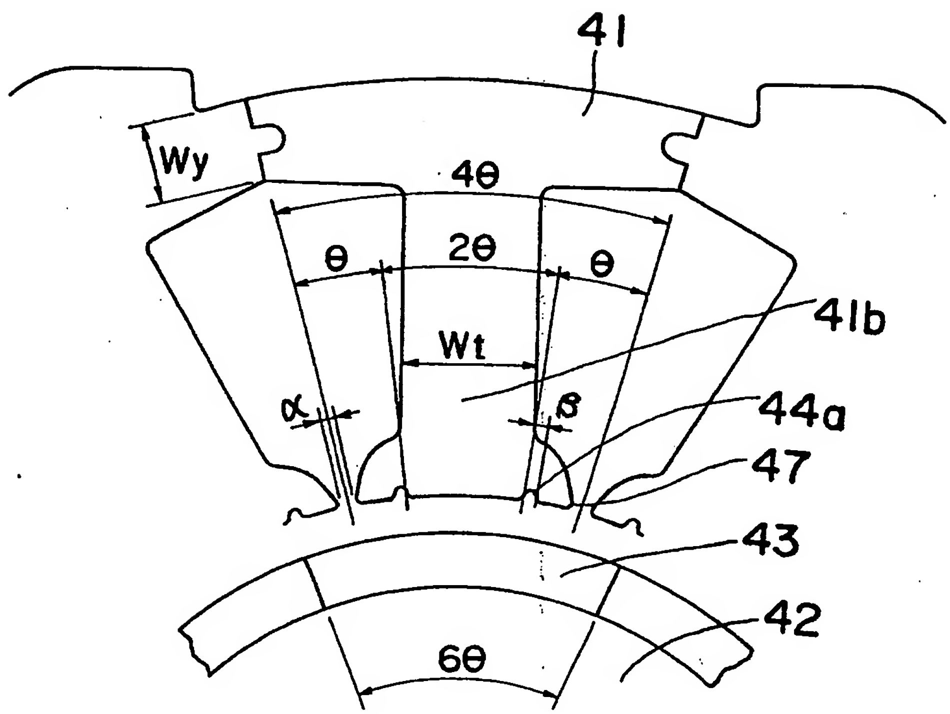
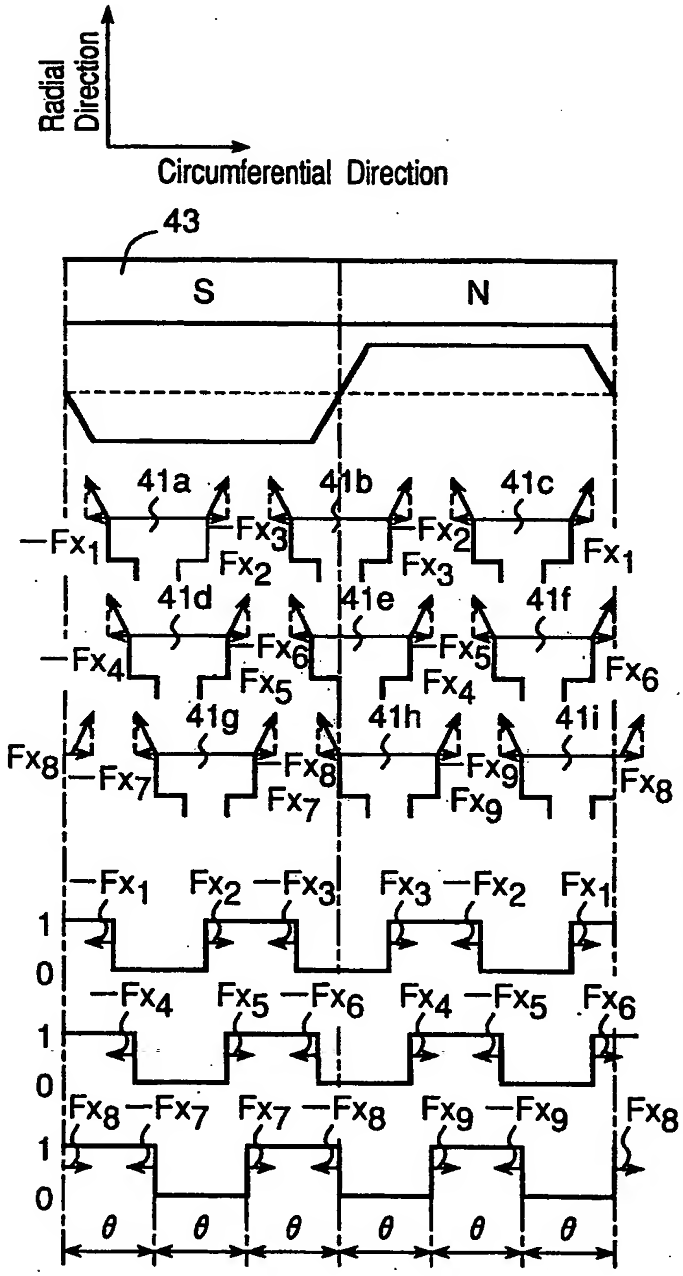


Fig.18



Permanent Magnet Magnetic Pole (a)

Air Gap Magnetic Flux Density (b) by permanent magnet

Stator Field Core (A)

Stator Field Core (B)

Stator Field Core (C)

Slot Function G_{10} of Stator Field Core (A) and Force Exerted in Circumferential Direction

Slot Function G_{20} of Stator Field Core (A) and Force Exerted in Circumferential Direction

Slot Function G_{30} of Stator Field Core (A) and Force Exerted in Circumferential Direction

Angular Distribution in Circumferential Direction

Fig.19

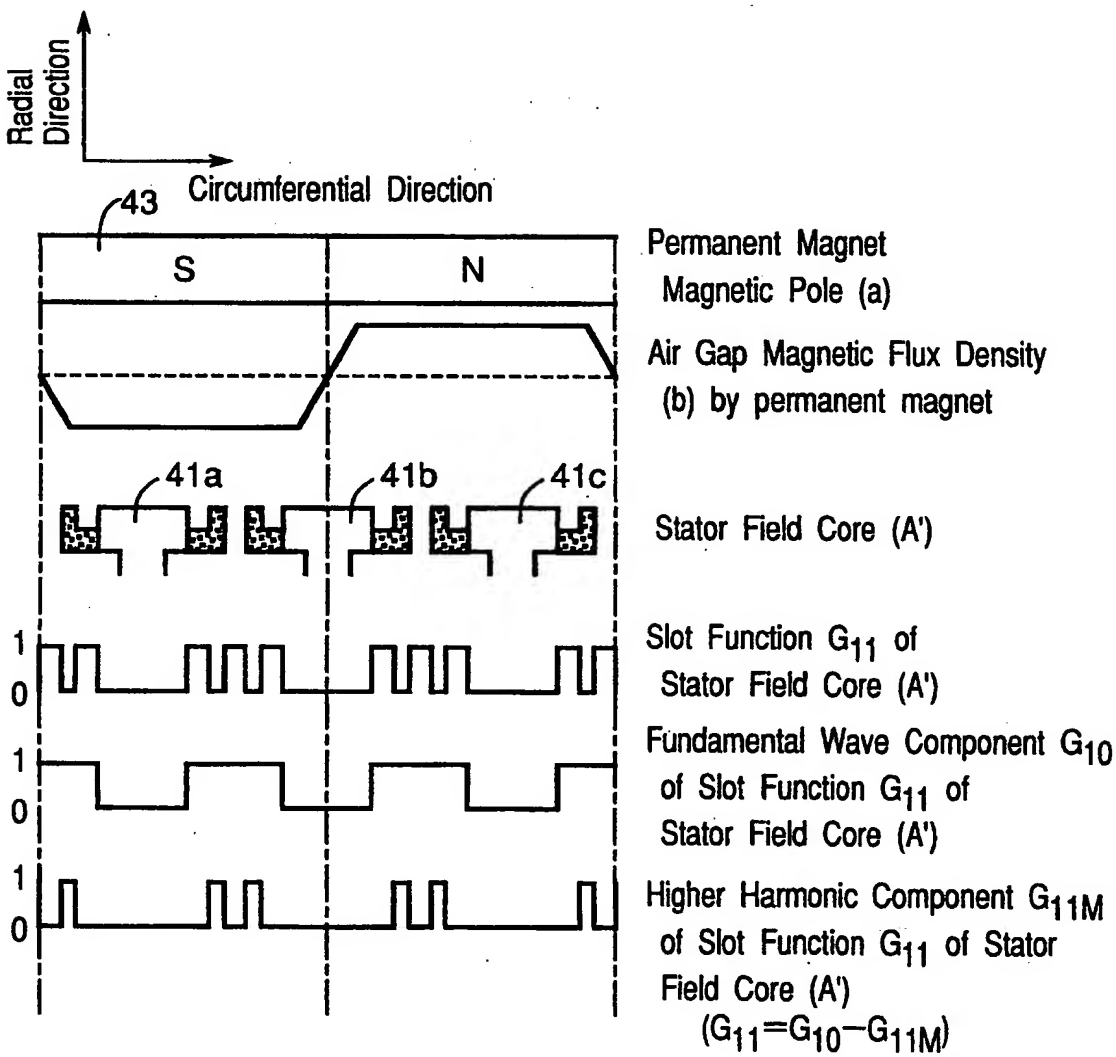

Radial Direction
Circumferential Direction
43
S
N
Permanent Magnet Magnetic Pole (a)
Air Gap Magnetic Flux Density (b) by permanent magnet
41a
41b
41c
Stator Field Core (A')
1
0
Slot Function G_{11} of Stator Field Core (A')
1
0
Fundamental Wave Component G_{10} of Slot Function G_{11} of Stator Field Core (A')
1
0
Higher Harmonic Component G_{11M} of Slot Function G_{11} of Stator Field Core (A')
$(G_{11}=G_{10}-G_{11M})$

Fig. 20

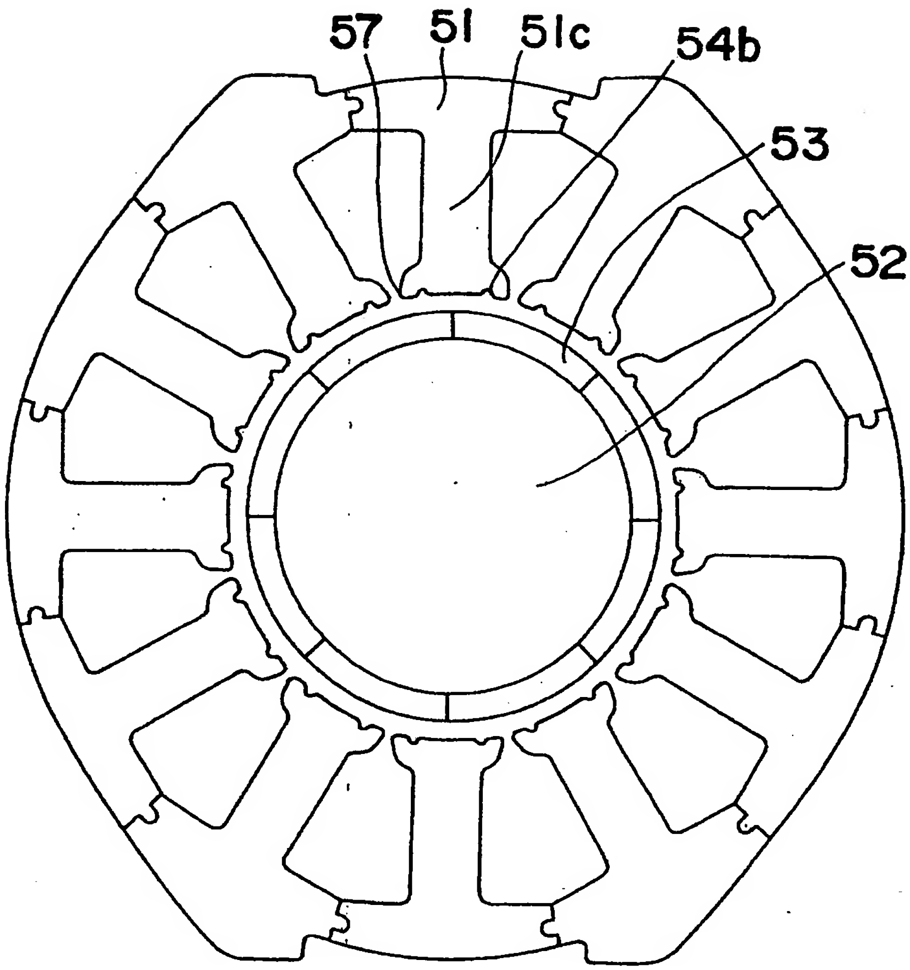


Fig. 21

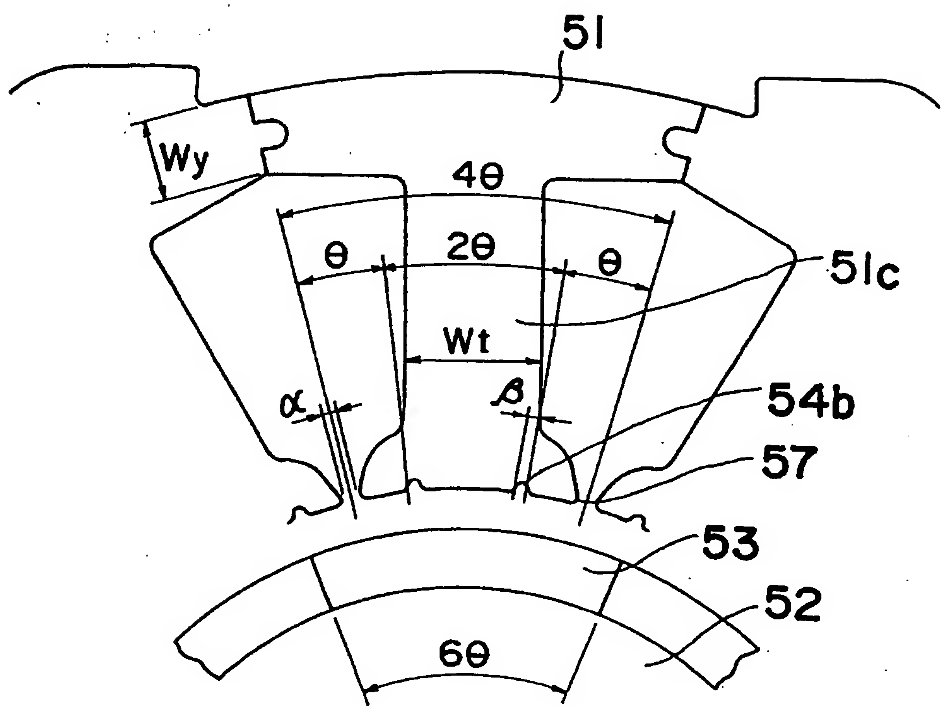


Fig.22

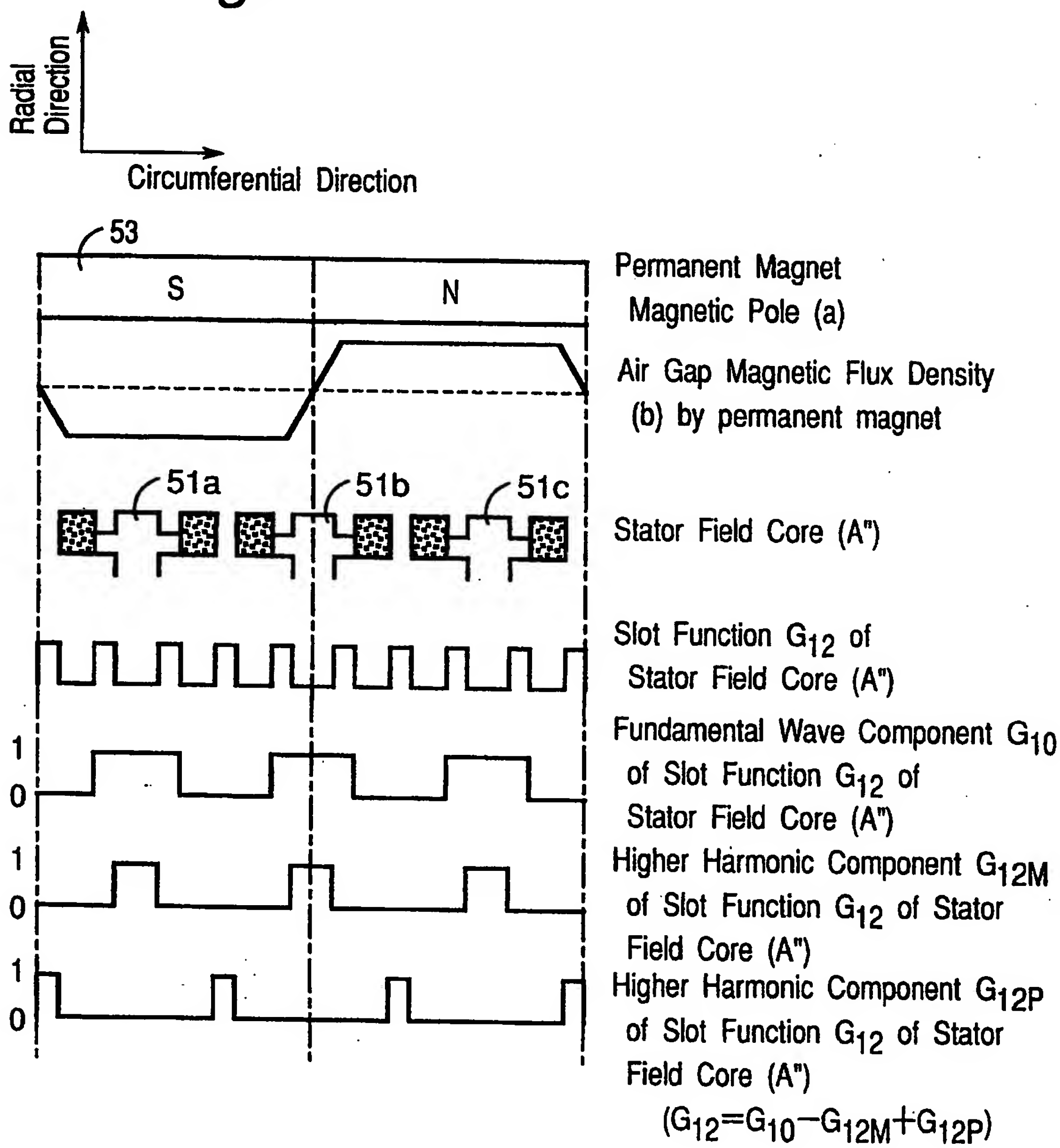

Radial Direction
Circumferential Direction
53
S
N
Permanent Magnet Magnetic Pole (a)
Air Gap Magnetic Flux Density (b) by permanent magnet
51a
51b
51c
Stator Field Core (A")
Slot Function G_{12} of Stator Field Core (A")
1
0
Fundamental Wave Component G_{10} of Slot Function G_{12} of Stator Field Core (A")
1
0
Higher Harmonic Component G_{12M} of Slot Function G_{12} of Stator Field Core (A")
1
0
Higher Harmonic Component G_{12P} of Slot Function G_{12} of Stator Field Core (A")
($G_{12}=G_{10}-G_{12M}+G_{12P}$)

Fig. 23A

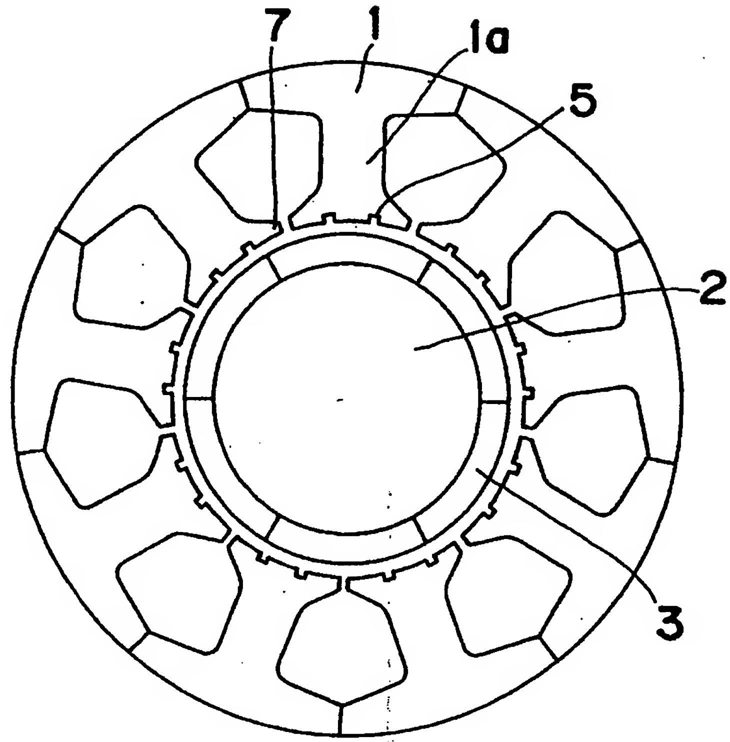


Fig. 23B

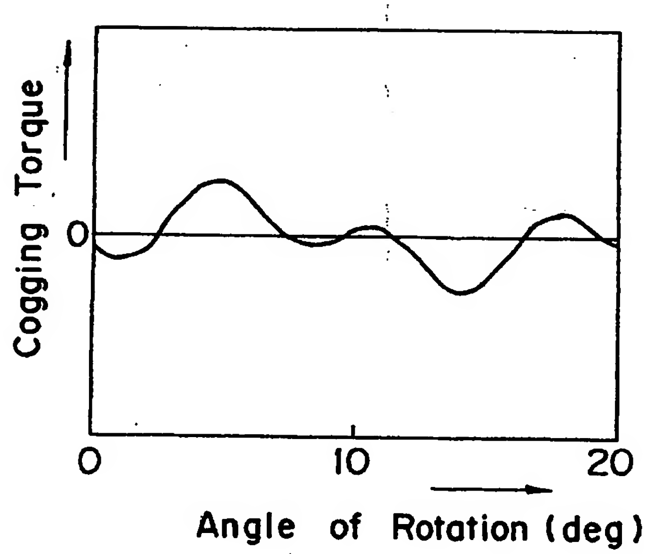
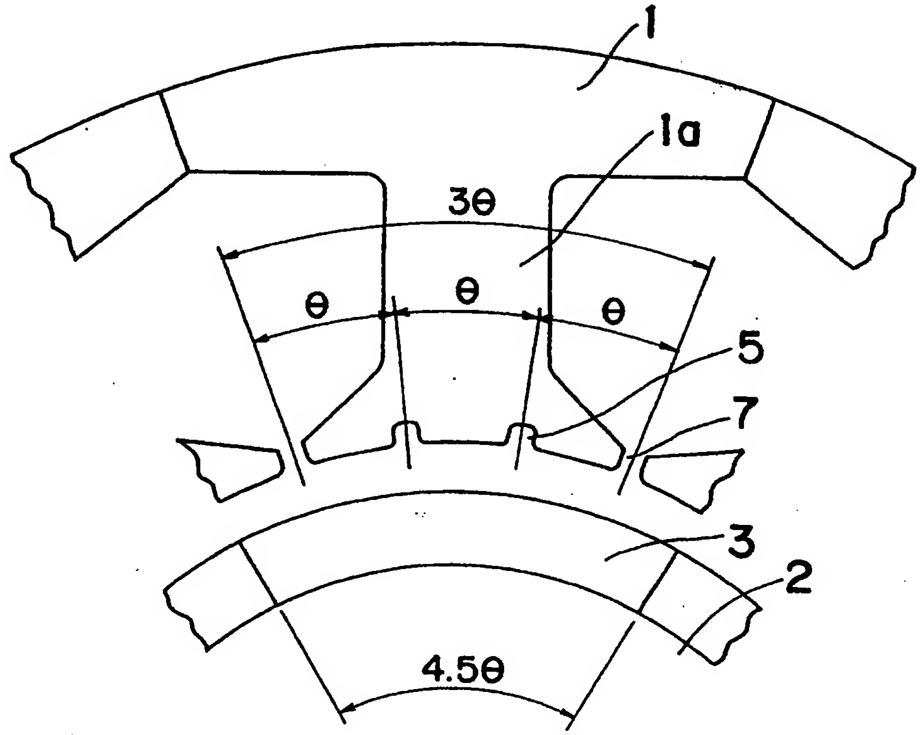


Fig. 24



INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP97/01732

A. CLASSIFICATION OF SUBJECT MATTER

Int. Cl^6 H02K21/16

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

Int. Cl^6 H02K21/12-21/24, H02K29/00-29/14, H02K1/14

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Jitsuyo Shinan Koho 1926 - 1997
Kokai Jitsuyo Shinan Koho 1971 - 1996
Toroku Jitsuyo Shinan Koho 1994 - 1997

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP, 7-147745, A (Seiko Epson Corp.), June 6, 1995 (06. 06. 95), Column 2, lines 16, 17, 37, 38; Fig. 14 (Family: none)	1, 13
Y		6 - 9
Y	JP, 4-76173, U (K.K. Kofu Meidensha), July 2, 1992 (02. 07. 92), Claim (Family: none)	6 - 9
EX	JP, 8-308198, A (NSK Ltd.), November 22, 1996 (22. 11. 96), Claim; Fig. 3 (Family: none)	2-5, 10, 11

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier document but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
August 12, 1997 (12. 08. 97)	August 26, 1997 (26. 08. 97)
Name and mailing address of the ISA/ Japanese Patent Office	Authorized officer
Facsimile No.	Telephone No.

Form PCT/ISA/210 (second sheet) (July 1992)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP97/01732

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☒ Claims Nos.: 12
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
In the modes 4 and 5 corresponding to the claim 12, the width of the salient pole section is an senseless value of about three times of the radius of the stator because since $\theta=7.5°$, $wt>3 \cdot r \cdot \cos\theta = r \cdot 2.97 \cdots$.

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest ☐ The additional search fees were accompanied by the applicant's protest.
☐ No protest accompanied the payment of additional search fees.

Form PCT/ISA/210 (continuation of first sheet (1)) (July 1992)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP00/00656

A. CLASSIFICATION OF SUBJECT MATTER

Int.Cl^7 H02K 1/14, 1/27, 19/10, 21/14, 29/00
H02P 6/18

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

Int.Cl^7 H02K 1/00~1/34, 19/10, 21/14, 29/00
H02P 6/18

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Jitsuyo Shinan Koho	1926-1996	Jitsuyo Shinan Toroku Koho	1996-2000
Kokai Jitsuyo Shinan Koho	1971-2000	Toroku Jitsuyo Shinan Koho	1994-2000

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
EX	JP, 11-98721, A (Toshiba Corporation), 09 April, 1999 (09.04.99), Full text (Family: none)	1-4
Y	US, 5, 670,836,A (Emerson Electric Co.), 23 September, 1997 (23.09.97), Full text & EP, 0676853, A2 & JP, 8-47192, A	1-5
Y	JP, 9-201022, A (BROTHER INDUSTRIES, LTD.), 31 July, 1997 (31.07.97), Full text (Family: none)	1-5
Y	JP, 8-251848, A (YASKAWA ELECTRIC CORPORATION), 27 September, 1996 (27.09.96), Full text (Family: none)	1-5
Y	JP, 10-313584, A (Matsushita Seiko Co., Ltd.), 24 November, 1998 (24.11.98), Full text (Family: none)	5
A	US, 4, 139,790,A (Reliance Electric Company),	1-5

☒ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
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"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search 04 April, 2000 (04.04.00)	Date of mailing of the international search report 11 April, 2000 (11.04.00)
Name and mailing address of the ISA/ Japanese Patent Office	Authorized officer
Facsimile No.	Telephone No.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP00/00656

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
	13 February, 1979 (13.02.79), Full text (Family: none)	
A	US, 4, 476,408,A (General Electric Company), 09 October, 1984 (09.10.84), Full text (Family: none)	1-5

国際調査報告

国際出願番号　ＰＣＴ／ＪＰ００／００６５６

Ａ．　発明の属する分野の分類（国際特許分類（ＩＰＣ））
Ｉｎｔ　Ｃｌ⁷　Ｈ０２Ｋ　１／１４，１／２７，１９／１０，２１／１４，２９／００
Ｈ０２Ｐ　６／１８

Ｂ．　調査を行った分野
調査を行った最小限資料（国際特許分類（ＩＰＣ））
Ｉｎｔ　Ｃｌ⁷　Ｈ０２Ｋ　１／００～１／３４，１９／１０，２１／１４，２９／００
Ｈ０２Ｐ　６／１８

最小限資料以外の資料で調査を行った分野に含まれるもの
日本国実用新案公報　１９２６－１９９６年
日本国公開実用新案公報　１９７１－２０００年
実用新案登録公報　１９９６－２０００年
登録実用新案公報　１９９４－２０００年

国際調査で使用した電子データベース（データベースの名称、調査に使用した用語）

Ｃ．　関連すると認められる文献

引用文献のカテゴリー＊	引用文献名　及び一部の箇所が関連するときは、その関連する箇所の表示	関連する請求の範囲の番号
ＥＸ	ＪＰ，１１－９８７２１，Ａ（株式会社東芝），９．４月．１９９９（０９．０４．９９）　全頁　（ファミリーなし）	１－４
Ｙ	ＵＳ，５，６７０，８３６，Ａ（Ｅｍｅｒｓｏｎ　Ｅｌｅｃｔｒｉｃ　Ｃｏ．），２３．９月．１９９７（２３．０９．９７）　全頁 ＆　ＥＰ，０６７６８５３，Ａ２ ＆　ＪＰ，８－４７１９２，Ａ	１－５
Ｙ	ＪＰ，９－２０１０２２，Ａ（ブラザー工業株式会社），３１．７月．１９９７（３１．０７．９７）　全頁　（ファミリーなし）	１－５

☒ Ｃ欄の続きにも文献が列挙されている。　　☐ パテントファミリーに関する別紙を参照。

＊　引用文献のカテゴリー
「Ａ」特に関連のある文献ではなく、一般的技術水準を示すもの
「Ｅ」国際出願日前の出願または特許であるが、国際出願日以後に公表されたもの
「Ｌ」優先権主張に疑義を提起する文献又は他の文献の発行日若しくは他の特別な理由を確立するために引用する文献（理由を付す）
「Ｏ」口頭による開示、使用、展示等に言及する文献
「Ｐ」国際出願日前で、かつ優先権の主張の基礎となる出願の日の後に公表された文献
「Ｔ」国際出願日又は優先日後に公表された文献であって出願と矛盾するものではなく、発明の原理又は理論の理解のために引用するもの
「Ｘ」特に関連のある文献であって、当該文献のみで発明の新規性又は進歩性がないと考えられるもの
「Ｙ」特に関連のある文献であって、当該文献と他の１以上の文献との、当業者にとって自明である組合せによって進歩性がないと考えられるもの
「＆」同一パテントファミリー文献

国際調査を完了した日 ０４．０４．００	国際調査報告の発送日　11.04.00
国際調査機関の名称及びあて先 日本国特許庁（ＩＳＡ／ＪＰ） 郵便番号１００－８９１５ 東京都千代田区霞が関三丁目４番３号	特許庁審査官（権限のある職員）　３Ｖ　９４２１ 小川　恭司 電話番号　０３－３５８１－１１０１　内線　３３５６

国際調査報告

国際出願番号　ＰＣＴ／ＪＰ００／００６５６

Ｃ（続き）．　関連すると認められる文献

引用文献のカテゴリー＊	引用文献名　及び一部の箇所が関連するときは、その関連する箇所の表示	関連する請求の範囲の番号
Ｙ	ＪＰ，８－２５１８４８，Ａ（株式会社安川電機），２７．９月．１９９６（２７．０９．９６）　全頁　（ファミリーなし）	１－５
Ｙ	ＪＰ，１０－３１３５８４，Ａ（松下精工株式会社），２４．１１月．１９９８（２４．１１．９８）　全頁　（ファミリーなし）	５
Ａ	ＵＳ，４，１３９，７９０，Ａ（Ｒｅｌｉａｎｃｅ　Ｅｌｅｃｔｒｉｃ　Ｃｏｍｐａｎｙ），１３．２月．１９７９（１３．０２．７９）　全頁　（ファミリーなし）	１－５
Ａ	ＵＳ，４，４７６，４０８，Ａ（Ｇｅｎｅｒａｌ　Ｅｌｅｃｔｒｉｃ　Ｃｏｍｐａｎｙ），９．１０月．１９８４（０９．１０．８４）　全頁　（ファミリーなし）	１－５